SOCIETY OF ENGINEERS

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G. A. PRYCE CUXSON

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PREMIUMS FOR 1893.

At a Meeting of the Society, held on February 12, 1894, the following Premiums of Books, &c., were awarded, viz.:—

The President's Premium (Gold Medal) to:

Professor Vivian B. Lewes, for his paper on "Gas Substitutes."

The Bessemer Premium to:

R. Nelson Boyd, for his paper on "Collieries and Colliery Engineering."

A Society's Premium to:

Robert Carey, for his paper on "Hydraulic Lifts."

A Society's Premium to:

E. G. Mawbey, for his paper on "The Leicester Main Drainage, &c., and the Construction and Testing of the Sewage Pumping Engines and Boilers."

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ESTABLISHED MAY 1854.

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THE TOWN HALL, WESTMINSTER, S.W.

1894

TRANSACTIONS, &c.

February 6th, 1893.

INAUGURAL ADDRESS.

By WILLIAM ANDREW McINTOSH VALON,
President.

The rapid development of the principles of engineering science, conducing as it does to the health, wealth, and longevity of the human race, cannot but be gratifying to all, and although the colossal achievements of eminent men for the time astonish the world, the everyday questions of water supply, sanitation, gas supply, the application of electricity, general municipal work, and the education of our young engineers, must hold the field in interest with the general public as with ourselves. In addressing you, therefore, it will be my endeavour to present to you some of these subjects for consideration, although it must necessarily be only the fringe of them I can possibly touch.

Without attempting to enter into the vexed question whether the responsibilities attending water supply are better discharged by municipal authorities or by companies, we may glance at the work of both, and form our opinions in accordance with the facts. The great city, in a part of which our present meeting is held, had until recently but little interest in a question of this kind, for no practical result could be the outcome of its discussion. But the advent of the County Council has in a measure cleared the ground for, when proved desirable, the united action of the entire Metropolis; and, although no doubt the present power of the Council is insufficient to allow it to adequately deal with the question, seeing that some of the out districts, as well as the central Corporation, are not under its jurisdiction, nevertheless, the fact of so much of the Metropolitan area being already under its control, may in the near future justify the extension of its power, so as to place it in a position to undertake the serious responsibility of the control of the

supply of water to such an immense district as London and its suburbs. In any case, the foremost question for decision—interesting alike to the consumer, the companies, and the Council—is the course that should be followed in providing for future requirements. Without attempting to discuss or criticise well-known proposals, profit may be derived from a consideration of suggestions, the result of observation and experience.

As is well known, the entire supply of the Metropolis is at present undertaken by companies, acting under restrictions and statutory powers, conferred by sundry Acts of Parliament. About half of the supply is obtained from the Thames, the rest being principally supplied by the Lea and New River, and by underground waters made available by pumping. The last-mentioned source—the underground waters—is to my mind the undeveloped, and, as yet, neglected means by which much might be done to improve the present, as well as to efficiently provide for the future supply.

Knowledge on this important subject has advanced rapidly during the last two or three decades—due principally to the vast development of railway communication, in the construction of the various lines in and about London, as well as the country surrounding. Thus the London, Chatham, and Dover line, with which some of us are well acquainted, begins in the London clay and terminates in the chalk, passing through the Weald clay at a low level in its course. Other lines converging on London traverse the whole of the beds of the London basin; and their construction has afforded valuable information on the underground waters surrounding the Metropolis. There seems, however, a tendency rather to annex a lake in some distant county, to supplement or supersede our present river supply, than to utilise these sources of pure water close at hand.

It will not be necessary for my present purpose to describe minutely the geological formation surrounding the Metropolis, nor to trace the lines of disturbance. If we but bear in mind that the Tertiary lies in divisions around London, north, south, east, and west; that the principal line of disturbance follows these divisions; and that the Metropolis itself stands at the south-east part of the north-western corner, it will give us a tolerably clear conception of its position, and convey to us that it does not stand in unbroken underground communication with the Tertiary strata surrounding it.

There are other lines of disturbance, the elevation or depression of which must have an important bearing on this subject when considered in detail; but for the present, we may, with this knowledge, assume these and proceed.

Mr. William Morris, Mem. Inst. C.E., has courteously

furnished information which enables me to say that the present limits of the Kent Water Company's supply extend over a total area of 178 miles; but about 30 square miles only is within the London district, the remainder being in the county of Kent. The original supply for the district was taken from the river Ravensbourne at Deptford, the undertaking being called the Ravensbourne Waterworks. It will be understood from this that at that time the original company was not of very great magnitude.

After the establishment of the Kent Water Company, the supply was continued from the river Ravensbourne until about the year 1855, when, the available flow proving insufficient, the Company supplemented it by sinking deep wells into the chalk on the site of their then existing works, which fortunately proved to be most favourably situated for this purpose. Finding the underground water to be of superior quality to that of the river, and more abundant in quantity, the river supply was in 1862 discarded, and the district wholly supplied from chalk wells.

This supply is obtained from wells and borings in the chalk, fed by rainfall on the North Downs and chalk district lying between the Ravensbourne and the river Thames. The chalk averages from 500 to 600 feet thick, and forms an immense underground reservoir, the overflow from which breaks out in numerous springs along the valleys of the Ravensbourne, the Cray, and the Darenth; whilst many springs flow directly into the lower Thames at Erith, Northfleet, and other places, where the river runs across the chalk formation.

The catchment area, including the chalk and other permeable strata which drain into it, is estimated at 110 square miles; and the rainfall on this area ranges from 24 inches per annum in the Thames valley to 36 inches on the North Downs—the latter rising to an elevation of from 700 to 800 feet above the sea-level.

In 1869 the Royal Commission reported that there was a large area of chalk at the south and east of London, forming a reservoir which did not feed either the Lea or the Thames above Hampton, as it contained surplus waters finding their way by innumerable springs into the Thames below London. From this reservoir, in all probability, large quantities might be drawn. They had not complete data as to what the available quantity would be; but taking into consideration the fact that the existing wells of the Kent Company, which were few in number, were then supplying above seven million gallons, and were said to be capable of yielding twice that amount, and that a further ten million gallons could be obtained from the

springs at Cray (a small district near Gravesend). they believed it to be a moderate estimate that, by means of proper works, an addition might be made from the source named of about thirty million gallons per day.

This report stated further that it was possible a considerable quantity of water, soft and of good quality, might be obtained in the neighbourhood of London by means of artesian wells in the lower green sand; and that the wells in the chalk formed an important auxiliary supply, and they might, no doubt, be considerably increased in Kent without interfering with the springs and valleys above London. It is worthy of note, also, that the Government Commission on the chemical quality of the water supply to the Metropolis, in their report of 1851, referred to the supply from the chalk as approaching nearest to the standard of all that is excellent in a town supply, worthy, if necessary, of the grandest efforts and works to procure and convey it; but the sources being near at hand, the water is obtainable without much difficulty or great expense. They added that, with such a noble application of the chalk spring water as the supply of the Metropolis, it would be a desecration to permit that water to be wasted.

In 1874, the Rivers Pollution Commission reported that the chalk constituted magnificent underground reservoirs, in which vast volumes of water were not only rendered pure and kept pure, but stored and preserved at a uniform temperature of about 10° Cent. (50° Fahr.), so as to be cool and refreshing in summer and far removed from the freezing point in winter. It would probably be impossible to devise, even regardless of expense, any artificial arrangement for the storage of water that could secure more favourable conditions than that naturally and gratuitously afforded by the chalk; and there was reason to believe that the more that stratum was drawn upon for its abundant and excellent water, the better would its qualities as a storage medium become.

The supply of such water to the Metropolis generally, either softened or unsoftened, would be a priceless boon; and would at once confer upon it absolute immunity from epidemics of cholera. There is no doubt that between London and the south, south-east, and south-west coasts there is an immense chalk area which might be made to yield an almost illimitable quantity of pure water. It has been demonstrated that there are very large quantities of water escaping into the Thames from the chalk, the Thanet sand, and porous Woolwich and Reading beds, along a line from Deptford to the west, past Erith and Northfleet to Cliff on the east. Mr. Marlow, as

far back as 1869, stated upon his experience in the construction of a local railway and experiments conducted by himself and Mr. Anstead, that as much as sixty million gallons of water per day might be obtained from the chalk by an intercepting tunnel along the line above described. My observations coincide with his, and my experience is such as to prove to me beyond doubt that intercepting tunnels in suitable positions at proper depths, made with care and attention, so as to prevent the escape of the chalk waters into the streams or sea, as the case may be, would be a source from which water, in such abundant quantity, and of so good a quality, might be derived for the supply of the Metropolis and the surrounding district, as to relieve us from any great anxiety and study of the question for a generation to come.

The question may be raised, How would the interception of this water affect the streams? The answer is that there are no streams of any magnitude to be affected in the districts named; and if there were, it is doubtful whether their scouring power would be much, if at all, reduced in the upper regions, as the water does not crop out in very large bulk until it is relieved from the pressure of the impervious soils in the bed of the river, and until the chalk crops up to the surface, as it does when approaching the mouths of the streams at their junction with the sea. This objection is not tenable, however, where the water finds its way through the chalk into the bed of the sea, which we shall notice presently.

Water must be abstracted from somewhere—whether that somewhere be Wales, Cumberland, or any other locality; and the loss of potable waters in these and other districts may at some future time be considered an irreparable calamity.

The greater portion of the rain which falls on a chalk formation, having no impervious beds intervening, continues to descend through various fissures until arrested by the gault or clay beneath the chalk, filling the lower cavities and accumulating to the height necessary to force it through subterraneous passages communicating with the sea. Under such conditions, an enormous quantity of water finds its way to the sea through the shore-line, between the levels of high and low tide, and in many places through the bed of the sea itself. Further, we find that, where the ground is undulating, it is a characteristic of the chalk formations which are covered by light porous soils, that heavy rain falling on the sides of these comparatively steep hills rapidly disappears below the surface, percolating and gravitating until upheld by the saturation of the chalk. It then gathers in such force in the interstices as to push its way

through the sides of the hills, or, descending into the valley, unites with the surface water to form streams. On the other hand, it will be understood that rain and moisture gathering on a clay soil are not absorbed; some is quickly returned into the atmosphere as vapour, part feeds the fields and trees, while the greater quantity drains off into rivers and streams. Hence the chief difference between a comparatively impervious soil, which results in the immediate formation of surface-streams of greater or less magnitude, and that of the chalk formation, which crops out close to the surface, without sufficient covering of top soil to intercept the rapid passage of moisture to the cells below. If to this is added its fissured condition, already noticed, it follows that absorption will take place so quickly as to clearly account for the absence of streams of any magnitude over such formations, there being a very limited amount of surface water available for their supply. For the same reason, evaporation is to a great extent checked, the water finding its way through the light soil, and gathering on the lower beds of impervious soils until an enormous natural reservoir is formed, of such depth that it is always full up to the nearest point where the chalk communicates with the sea; and this point of communication for all practical purposes may be taken at the mean between high- and low-water mark.

But the reasoning necessary to establish the foregoing facts, carries with it others which are of equal importance, viz. that, wherever the chalk assumes a hill form, or is built up at a higher level, surrounded by permeable soils, it naturally follows that, the zone of saturation being reached, it will discharge itself at any easier or more ready outlet than the sea-level. It will also to some extent account for the puzzling difference of height at which water is found standing in wells in the neighbourhood of London; as well as the more or less ease with which they can be lowered by continued pumping at elevations above sea level. The following particulars given by Mr. T. H. Martin, Engineer to the Barnet Water Company, are recorded as bearing on the above.

The area of the district supplied by the Company is 46·7 square miles. The supply is obtained 164 feet below the surface from deep wells sunk into the chalk. There is the pumping-station at New Barnet (Herts), 213 feet above Ordnance datum, situated on the London clay, and within 4 miles in a north-westerly direction of the district of South Mimms, where the chalk crops out and extends for about 18 miles in an east, north-east, and northerly direction, partly covered by drift. The rainfall over this area averages 26·75 inches per annum. At New Barnet there are three wells connected by adits: No. 1,

191 feet deep; No. 2, 234 feet deep; and No. 3, 252 feet 6 inches deep. The district varies greatly in character, a large portion being entirely agricultural, as shown by the estimated number of inhabited houses being 8402, while the area is 29,888 acres. The chalk through which the wells have been sunk and adits driven is porous, though moderately compact, no large fissures having been found; but the supply of water is abundant. The height, however, to which it rises by the cessation of pumping, has fallen considerably, in common with the whole of the wells within the London basin; showing that the line of saturation has been lowered through the continued drain upon the underground water. Still, Mr. Martin is of opinion that the abundant supply now obtained can be augmented as required.

Swallow-holes exist at South Mimms, where the water runs direct into the chalk. They are said to take the rainfall of 20 square miles; but this has not been found to be quite correct. It is true in dry weather the stream of water wholly disappears at these swallow-holes; but in wet weather they are insufficient in capacity to take the whole body of water, and the greater part flows by, into the Colne. It is doubtful whether the water that thus passes direct into the chalk flows towards the Lea or Colne; but in time of flood, the spring water at Amwell has been noticed to be turbid, thus indicating a somewhat direct communication between the spring and surface waters in a north-easterly direction towards the Lea.

The East London Waterworks Company, under the direction of their engineer, Mr. W. B. Bryan, Mem. Inst. C.E., have executed, within the past six or seven years, very large works for obtaining water from the chalk formation. At Lea Bridge alone, they have driven nearly 7000 feet of heading. At Walthamstow, where works are in progress, about 700 feet have been driven; and at Waltham Abbey, about 600 feet. The results vary; but the company's success has been very great.

At Richmond, in Surrey, the Corporation are still actively pursuing the search for water, by tunnelling in the chalk at a depth of nearly 400 feet; and they have succeeded in cutting through several fairly good fissures. An inspection made a few weeks ago with Mr. W. B. Bryan, and the borough water engineer, Mr. W. G. Peirce, one of our Vice-presidents, resulted in a recommendation to the Corporation to pursue the excavations. Evidence was afterwards given at the Local Government Board inquiry confirming this proposal; and it is believed a good supply of water will be found.

A description of the water supply taken from the chalk for a coast town, will furnish considerable evidence of the truth or

error of many of the statements already made. Ramsgate which, as is well known, derives its water from the chalk, fronts the sea at the south-east corner of Thanet, the town stretching for about $1\frac{1}{2}$ miles inland. At this distance from the sea, there is a slight depression in the tableland named Whitehall; and it is here the principal pumping station is erected, at an elevation of about 99 feet above sea-level, and about 83 feet below the highest part of the surrounding country—the town of Ramsgate varying in its levels to the extent of 155 feet.

The pumping well is sunk to the level of mean water mark; and the headings are continued right and left in a north-westerly and south-easterly direction, cutting the fissures of chalk at right angles, which would allow the water to flow in and accumulate until the headings were full, if pumping operations did not go on in the meantime. The headings are not water-tight, the water being as free to flow out as to flow in. As a matter of fact, however, it gathers to a considerable height before passing out, the reason being the natural one, viz. that the continuity of the flow being disturbed by the open heading, it must gather sufficient strength before it can continue its onward course to the sea. This one heading is about a mile in length, and contains, when two-thirds full, a million gallons of water. It yields daily in the summer-time about 800,000 gallons; and if emptied at night, refills in about ten hours.

These headings are about to be extended in a south-westerly direction towards Minster, directly alongside the South Eastern Railway, the direction of this line crossing the fissures of chalk as nearly as possible at right angles. By the benched shape of the tunnels it is possible to drive any distance without raising the level of the bottom. This simple contrivance surmounts what was at one time a serious difficulty in water tunnelling. The nature of the chalk through which these headings are driven is of a varied character: for a limited distance, a close, solid, limestone-like formation will obtain; after which for a distance will be chalk, so loosely piled together, that it requires timber supports to sustain the arched form of the roof; while adjoining this will occur that rock-like and fissured arrangement, through which the bulk of the water is conveyed to the cross cutting. The gathering ground for Ramsgate is a fairly large one, embracing more than half the area of the Isle of Thanet.

After careful study, one cannot but conclude that a sufficient quantity of water could be obtained from the district between London and the south coast in a more or less direct line, and the coast east of this line, for the supply of a great part of the Metropolis, without injuriously affecting or materially diminishing existing streams. Indeed, the Cray, a tributary of the

Darenth, is the only stream between London and Strood that has its rise in the chalk district; and it conveys a very small part of the rainfall into the Thames. Hence it is certain that the water of the district of the North Downs runs into the Thames between high and low water mark, as proved by the shallow wells sunk in the shore line from Woolwich to Gravesend, from which pure fresh water is drawn for the supply of shipping. An equal absence of surface drainage is to be observed between Strood, Herne Bay, Ramsgate, Dover, and Brighton; while at all these points copious floods of water escape into the sea, as also considerable quantities at the outcrop of the chalk at the foot of Sevenoaks and Shoreham Hills.

Taking the average annual rainfall at 25 inches on the North Downs and the district east and west of the Medway which finally drains into the Thames, and the area of chalk exposed or covered by the usual permeable soil at 450 square miles, and allowing (say) one-third for evaporation, surface drainage, and vegetable absorption, this would leave a quantity equal to more than 600,000 gallons per mile per day to infiltrate. This would amount to a quantity of water available for this district alone of 270 million gallons per diem; and the fact is worth recording that careful estimation shows that the exposed superficial beds and surface of the chalk surrounding the Metropolis, including outliers of the Tertiaries, may be taken at 2100 square miles. If the percolation is estimated to be 10 inches per annum, this equals an addition to the water stored in the chalk of 840 million gallons per day.

In considering the subject of the water supply to the Metropolis as a whole, many important questions present themselves beyond that of the possible future source of supply. There can be no doubt that any supply of water to be satisfactory must be constant. This fact, although long ago recognised and accepted, is not yet an universal condition of the existing arrangements made by the companies. Indeed, in 1870 the whole supply was practically intermittent; and at the moment of writing, little more than one-half the area supplied by the water companies can be said to be in a different position. This is perhaps one of the most irritating facts in connection with the supply given by the companies, tending more to create dissatisfaction than any other.

No doubt the companies might at once comply with the demand for an entire constant service, if not restrained by a fear of greater waste—a fear by no means unnatural, when by the present system, on an average, nearly 33 gallons per head of the population passes through the mains, being more than double the quantity that is absolutely necessary for a full

domestic supply, including what is used for sanitary and manufacturing purposes. If this be so, one-half the water delivered into the mains is wasted, and serves no useful end, not even from a sanitary standpoint. Indeed, the reverse is the case. The enormous cost of gathering and distributing, together with the capital to construct the necessary works, forms an item startling in its dimensions; and it is clear, in my opinion, that but a fraction of the annual amount expended to raise and distribute this waste would be required for the purpose of efficiently guarding against such waste by maintaining mains, services, and distributary apparatus in perfect and reliable order throughout.

This is proved beyond doubt by the experience gained in provincial towns, where any company or local authority have had the courage to pioneer the way of constant supply, giving to the inhabitants the inestimable advantage of preservation of health, with a decreased annual expenditure through economy in working; at the same time providing an unsleeping protection from damage to property by fire. The pressure maintained in the mains should at all times be constant and sufficient; fire engines would then be unnecessary, and each householder, if he pleased, could protect himself by having a fire hydrant fixed immediately opposite his door, or directly on his premises, as the case may be.

The town of Ramsgate was one of the earliest to adopt a system of constant supply. In 1877 the then water company sold their undertaking to the local authority. At that time the supply was intermittent, indeed, it may be said very intermittent, the upper levels being entirely without water until quite late in the afternoon. These levels were reached by means of pumping against a weighted valve. The water could not rise to the overflow reservoir, which was itself situated at an elevation considerably below the highest level, until all the valves on mains supplying lower levels had been closed; and in this way the pressure was allowed to gradually gather sufficient force to press the water against the weighted valve, and so supply the mains in the higher district.

This was a crude and unsatisfactory method of procedure, and in case of fire was inconvenient as well as dangerous; but it served to hasten the constant supply. Immediately after the transfer of the works instructions were given to proceed with the necessary works for the purpose of a constant supply. The headings were extended; mains and services overhauled; a brickwork tower, 60 feet high, constructed at the highest point, with a cast-iron tank 10 feet deep, holding a quarter of a million gallons; and a new pumping main laid to connect it

with the pumping station situate about a mile and a half inland. In 1879 the water was turned into the high reservoir, and during the week succeeding all the mains in the town and district were brought under constant pressure, and have remained so ever since. Ramsgate being a hilly place, the system adopted was one of high and low service, the mains being joined together at certain points, but separated by valves. If necessary, these valves are opened and the high service connected to the low for the time being.

So efficient has the supply proved itself that, although many fires have broken out during the past fourteen years, none have caused damage to any considerable extent. The firemen, who are well drilled and organised, are provided with a hand-barrow with flexible screw hose, and a hydrant key, and with this simple arrangement are quickly on the spot, and in a few minutes fires which under ordinary circumstances would cause grave mischief are absolutely washed out. Contrast this with the costly arrangements and water-wasting system existing in London. The maintenance of divisional fire stations, furnished with expensive machinery, which must be moved from place to place to the danger of life and the interruption of ordinary traffic, and the enormous quantity of water unavoidably wasted by the temporary arrangements needed to supply these engines, when all has been done that skill can devise, will give but a tithe of the efficiency that can be obtained from a common cast-iron main of proper dimensions kept under an unvarying head of water by the natural means of bulk at a higher point. It seems to be accepted without question, by those who have not tried it, that the adoption of a constant supply means waste of a prohibitory kind. My experience does not point to any such conclusion—indeed, controverts it. While the company at Ramsgate were giving an imperfect intermittent supply, the consumption per fixed head of the population rose to over 32 gallons. In 1879, after the constant supply was first installed, sufficient time had not elapsed to allow the old mains and services to be completely overhauled, the only precaution resorted to being that all waste pipes should be taken out of the cisterns and warning pipes substituted in their place. In the majority of cases these waste pipes had been directly connected to the soil pipes. The result was to bring down the consumption of water per head of the population from 32 gallons to 25 gallons. This was subsequently further reduced by a thorough overhaul of the mains and services and a proper system of valves, to 17 gallons per head, at which it has since remained, with a very slight alteration, for nearly fourteen years.

In a season town like Ramsgate, great care is needed to accurately arrive at the water used per unit of the inhabitants. The winter population of 30,000 is for a considerable part of the summer increased to nearly 90,000; and at that time it is hardly necessary to say the consumption per fixed head of the population rises considerably, but nothing like in proportion to the extra number of people supplied. This would seem to prove beyond doubt that ordinary waste from apparatus, &c., is more considerable than we give it credit for, seeing that so long as the number of mains, services, and apparatus for supplying water are not augmented, the increase in number of those taking water for a time through existing apparatus, bears a proportion equal to one-third only of the quantity taken by the fixed population. That is to say, during the winter the water consumed for all purposes by the population of 30,000 is 17 gallons per head; and in the summer, when the population is increased to 90,000, the consumption equals 36 gallons per head of the fixed population of 30,000; this includes the additional water used for roads, flushing, and gardens, not required during the winter months.

This question of waste is a large one, reaching far in its effect into every phase of water supply; and its reduction can only be effected by some determined and united effort on the part of water engineers. The enormous expenditure incurred in raising, storing, and distributing this waste has already been referred to; the expenditure to dispose of it must be relatively as large, while the required capital to initiate and maintain works capable of either pumping or impounding this lost quantity should certainly not be expended until the present supply is intelligently used.

The system of inspection as ordinarily performed must be considered a failure. Improvements have from time to time been introduced into a faulty system; and some relief has followed, too often to be soon after neutralised by relaxed effort, caused by the confidence inspired by a first success, and the failure of continued and untiring watchfulness, which in practice it is very difficult to efficiently maintain.

Some few years since the Corporation of Ramsgate was called upon by the rural sanitary authority to extend its mains a distance of six miles beyond the municipal boundary; and, as the district referred to was within the limits of supply granted to the Corporation by the Act, they complied.

After the work was completed, and as the services were in some number connected, the extreme difficulty of efficient inspection to a district wide of the centre was felt; the more so as many of the consumers were farmers, market gardeners,

and so on, who at certain periods of the year had a use for water other than for domestic purposes, and used it accordingly, generally without leave.

Efforts made by the inspectors to check this unaccounted-for waste were not successful, and it was therefore thought advisable to supply these customers through a meter, under an agreement that so many thousand gallons as a maximum quantity should be allowed to each consumer according to the amount at which his property was rated, an additional charge at the usual price per 1000 gallons for manufacturing purposes to be made for any quantity exceeding the maximum agreed upon. This plan was successful, saving labour and giving satisfaction to both supplier and user.

It is not claimed that the practical experiment just related fulfils all the conditions necessary to successfully supply water by meter, as circumstances would not justify its being applied to general purposes without the attendant rules being carefully thought out. The success it met with, however, may be taken as an indication of what might be a reliable way of dealing with this most difficult subject, if only surrounded by the necessary safeguards which would be insisted upon by Parliament apart from any economical reasons. Any attempt to present a Bill embodying the supply of water by meter would receive scant favour from a Parliamentary Committee, unless, at the same time, it could be shown that for all useful purposes the supply would be practically unlimited, and that the cost of supply to the poor would be such as not to deter them from its ample and free use. It is my opinion that both these conditions may be fully complied with while measuring and regulating the supply by meter.

There are many and weighty reasons which can be, and are, given for a continuance of the present method of levying a rate to provide payment for the supply of water, but perhaps the two most complete are :—

(1) The necessity that a plentiful supply at a low rate should be given to small properties or buildings inhabited by people in poor circumstances; and (2) that this is an equally essential condition to the "well-to-do" in order that the health of the whole community, rich and poor alike, may be protected, and not allowed to suffer from bad sanitation in any part of a connected district.

It is not therefore proposed to interfere with the present mode of payment, so far as the rating of property for the water consumed is concerned; but by observation and calculation it has been found that among houses, small and large, an estimated quantity at the rate of 10 gallons per room per day on an

average to each tenement, leaves a large margin over and above what is required for all purposes of domestic supply.

Now if this quantity be taken as the basis of supply, a few figures will prove that, while it secures an ample quantity to cottages, small properties, and buildings occupied by the poorer classes, the larger mansions will be equally well cared for.

It may be urged that in most towns in all crowded quarters there are to be found many tenements, large and small, where each room is occupied by from two to six persons, and that here the 10 gallon limit would not apply. But it is just such cases of overcrowding that would justify the regulation. Owners of this class of property are responsible for the water consumed by their tenants; and while the tenant would have no restriction to the free use of water, the extra payment demanded at the end of the quarter from the proprietor would give him a greater interest in the habits of the occupiers of his premises, and perhaps lead him to give a more conscientious supervision of the duties he assumes as the possessor of house property, which may be a little troublesome, but is correspondingly profitable.

If the quantity allowed were adjusted at the end of each quarter, and there had been no excess, no additional charge could be made; but if the maximum had been exceeded, then the additional quantity would be paid for, at the rate charged for water per thousand gallons for manufacturing purposes.

This quarterly striking of the balance would leave no room for carelessness; and only a short discipline would be necessary to bring the consumers in line with the system.

Questions of detail, such as what area should be agreed as sufficient to be reckoned as a room, or, when a room was of very large area, whether it should be calculated as two or more, would easily be adjusted. The difficult question, however, to which attention will next be called is the selection of a reliable measurer.

It is not within the scope of my present intention to enter into the merits or demerits of any particular water-meter. My remarks will generally apply to the various classes of meters now competing for favour, each claiming, no doubt justly, many points of excellence; but it is just the intelligent appreciation of these particular points of excellence, in the division or class to which they belong, on which success in their use entirely depends.

During the last fifty years a thousand designs of one kind or another in the various classes of water-meters have seen the light. All of these can be grouped under one or other of the following heads:—

(1) Low-pressure meters;

(2) Inferential meters of various types;

(3) Positive meters of the reciprocating piston principle, with single and double cylinders;

(4) Diaphragm meters;

(5) Rotary piston meters.

In each of these classes there are manufactured meters having many good points and a few defects. It is impossible to say of any of them that they are perfect; but, given a fair knowledge of the construction of each kind, with a judicious selection of the meter best adapted to the work it has to perform, it will be found that practical accuracy in measurement will result.

In domestic supply our attention should be directed

(1) To the nature of the water to be dealt with;

(2) If it is to be a constant or an intermittent supply;

(3) Whether cisterns are to be wholly used, partly used, or completely cleared away, thus drawing the water direct from the main.

These points being understood, the meter selected should be considered

(1) In its relation to its efficiency for the work required of it;

(2) As to the cost.

But, having regard to these two latter considerations, the most suitable meter, which does its work most perfectly at the lowest cost, should undoubtedly be chosen.

Great care is required to fix on any particular meter to give accurate results where there is a constant supply without cisterns, due to the loss of head at the outlet; but generally it will be found that the advantages offered by the best form of rotary piston for this kind of work will put other classes at a disadvantage.

Our experience in England with the domestic meter is not of sufficient extent to allow a complete reference; but in America, where, if anywhere, water might be expected to be freely wasted, the domestic meter is in many places in full operation, giving satisfaction to both the company and consumer.

In passing from the water question to that of sanitation, a wide field is open to view, the 3000 miles of sewers by which this great city is drained—ranging from a small size to 13 feet in diameter—conveying by water carriage offensive matter of all kinds, and providing the necessary conduit for the rainfall, when looked at as a complete scheme requires an effort of the imagination to comprehend. Works of a similar kind in other towns appear puny by contrast, though they are in themselves

by no means insignificant. The daily discharge at the common outfall of the mighty flood of filth, gathered from all quarters of the great metropolis, and the manner of its disposal, crude and faulty though it be, baffles the powers of the imagination. Yet all must sincerely desire that the time may soon arrive when some practicable, if not strictly economical, system may be devised, by which this daily waste shall be recovered and returned in an innocuous and useful form; for most surely, no such guilty extravagance as is at present practised, can be indulged in for any very considerable time, without retaliation from natural causes of a kind not at present realisable.

We need not, however, be surprised or disheartened if we are not yet perfect in the inception and completion of our sanitary arrangements. It is little more than half a century ago that drains were used for the sole purpose of conveying rain water, and the cesspit was the common recognised receptacle for domestic sewage. The closet of the day drained into these; and as it was imagined that the effluent was not very harmful, these cesspits were in turn allowed to overflow into the nearest stream.

A rapidly increasing population, and a better means of observing mortality, supplied by the passing of a compulsory Registration Act, led the authorities to take notice of an increasing death rate; and in 1848, the Public Health Act was passed, giving, however, but a limited permissive power of inspection to local bodies.

The introduction of the system of tubular drainage brought in its train the usual crop of attendant evils which surround all the untried artificial methods devised to overcome a greater evil. The great teacher "experience," soon demonstrated that air-tight tubes connected to any sanitary arrangement served to confine the gas driven off at low temperatures only until such time as it could find its way into the dwellings these tubes were intended to protect, and intensify disease rather than relieve it.

The report of Sir Robert Rawlinson on the drainage of Dover, which was the first town to come under the provisions of the Act of 1848, served the useful purpose of clearing the ground, and exposing much error existing on a subject which at that time was but little understood. At this date, the use of glazed stoneware pipes as conduits to the larger or main sewers, may be said to have been fairly introduced.

The system of house drain ventilation has of late years made rapid strides towards perfection, not, however, before an increase in the death rate proved beyond dispute the imperfections attending untrapped and unventilated tubular drainage.

As already intimated, the gas freely generated in the closed tubes was, by a natural law, forced through sinks and receptacles into the living rooms of connected houses; and the attempt to keep it back by water-sealed syphons proved ineffectual. The Local Government Board, brought face to face with so great a difficulty, recommended that all pipes conveying sewage to the main drain should have open joints, with the intention, it was thought, of providing drainage for the land through which the pipes passed, and by these means obtaining an additional cleansing power. This hurriedly decided upon mistake has only disappeared of late years. Sound joints are now universally insisted upon; while well ventilated intercepting traps are used for house drainage, which if properly arranged effectually protect the houses from sewer contamination.

There is, however, much left to be desired in our mode of conducting liquid sewage to the point of discharge. The lessons taught by experience have not been properly improved upon. It has been shown beyond question, that water-carried sewage, while freely exposed to air currents, if kept in constant motion to the point of discharge, is comparatively harmless; but nevertheless, enough has not been done to secure by simple means this desirable end. In the case of main drains, we are still too much exercised about keeping the general public in ignorance of their locality, instead of educating them as to their innocence, when intelligently and properly handled.

With regard to house connections and subsidiary drains, the importance of their complete ventilation should be urged by every responsible sanitary authority, with every means they can devise for convincing the mind and judgment of the householder, by the dissemination of simple and comprehensible information; but, if necessary, it should be pushed home by the force of the law on all ignorant or stubborn people, who are a permanent danger to the community.

The system of aerating drains and sewers being now better understood, the public health renders it imperative that all permissive legislation should give place to compulsory; public authorities should have powers to enable them to compel every person who connects his house to the public sewer, to do so in accordance with a submitted plan to be approved by, and carried out under the supervision of the public officer specially appointed for that purpose. This plan should contain every point of detail relating to sinks, closets, rainwater pipes, tanks, and overflows.

Take an illustration: at the present moment, there is no law to compel any person to provide ventilation to his house

drain; and there are many scores of thousands of people connected with the sewer, who do not even know what it means. Others, who do know ventilation is desirable, are as a rule in the hands of builders and sanitary plumbers, who themselves are only commencing to appreciate its importance.

It is impossible to instruct these thousands of householders without direct positive legislation and watchful activity on the part of local authorities, combined with the intervention of an educated sanitary engineer as inspector, armed with the necessary arbitrary power.

There can be no manner of doubt, that every house connected with a subsidiary drain, should be compelled to provide a ventilating pipe to the drain side of the intercepting trap, as well as the house side. If this were made universal, no serious ferment could be set up in the tubes conveying the sewage; and, if any noxious gases were generated, they would be immediately relieved, oxidised, and dispersed by natural means.

But a sweeping proposition of this kind could never be executed without powers of compulsion behind, as opposition might reasonably be expected from those householders already attached; and the rule, to be effectual, must be universal. The cost of such alteration, if houses were already connected, would be inconsiderable; and it would add but little to the cost of a new connection. There must be no trifling. Every house in communication with the sewer should be compelled to have a ventilating pipe before and after the intercepting trap, carried to the top of the adjoining building, to a height sufficient to clear the ridge of the roof, and to be in such a position as to avoid sewer air descending flues of adjoining chimneys, or to admit of its entering open windows.

After years of discussion and enlightenment, the importance of good drainage has been firmly established in the public mind, and recognised by municipal authorities in all parts of the United Kingdom. Drainage works have been proceeding apace. All towns of any importance, especially those which are regarded as health resorts on the coast, have vied with each other in obtaining a verdict from the general public in their favour.

After twenty years of reporting, the town of Margate has completed an expensive system of drainage, which will go far towards establishing it in the favour of the visiting public. Hitherto, the whole town relied entirely upon cesspits as the mode of disposing of their sewage.

Ramsgate—which has been drained for the last 25 years—a short time since completed a first-rate system of main drainage, by taking the outfall well into the sea, and attaching

the inner basin of the harbour to form an immense flushing tank. To lower the water of this tank for an inch or two means the scouring power of several million gallons of water along the whole line of the main drain to the point of discharge. Few towns have the advantage of ensuring at all times a well-flushed outfall, as is the case of Ramsgate.

The result on the health of the town has been of a most satisfactory kind, of which its low death-rate is proof, notwithstanding the annual immigration of thousands who are seeking to recover health from recent illness.

Other towns have been or are similarly engaged in thus protecting themselves; and it need hardly be added that all money judiciously spent for this purpose is well expended.

Other municipal works of considerable interest are at present under construction at Dover and Ramsgate. Those of the latter town were referred to by your President in his last year's Address. To those remarks can now be added that the work which at that time was only proposed, is now considerably advanced towards completion; and may it be my pleasure to meet you at Ramsgate during the summer months at one of your professional visits.

The work from which most difficulty was apprehended was the construction of the new sea-wall across the Inner Harbour. It was determined to do this work between the rise and fall of the tide, rather than incur the large expense for damming. It has been carried to a successful issue, notwithstanding the existence of springs of considerable size running out from the cliffs. These were gathered up into glazed pipes, laid in the centre under the foundation of the wall, and allowed to discharge at a low point by gravitation, or pumped when necessary by centrifugal pumps. The foundations, wall, and counterforts are solid concrete to Ordnance datum: and from this point the wall is faced with Portland stone removed from the old wall, backed in with concrete and coped with granite two feet deep, covering the entire thickness of the new wall.

Although this wall cuts off a part of the inner basin, it will, as a matter of fact, provide greater accommodation for shipping, as part of the work consists of deepening the inner harbour, in order that vessels may berth alongside the whole length of the quay. The rising road is carried on arches. These have the principal part of their foundation on the old military road wall. The made piers, foundations, and walls to the springing are solid concrete, the arches being turned in brick and cement, with a vertical bond throughout, and worked with ornamental facing to the front of the arches and cement piers, so as to give when complete the appearance of an ornamental brick-

work construction. As will be understood, the road is not a level viaduct, but descends at an uniform gradient of 1 in 25, until it reaches the centre of the town, fronting the sea. From that point it rises to the east, following the natural conformation of the ground, until the highest part is reached; and to do this it is necessary to remove an hotel with a frontage of 132 feet, which has been acquired for the purpose. The whole work when complete will connect the east and west cliffs by a roadway 2500 feet long, varying in width from 45 to 70 feet. The improvement also embraces the widening of the lower or level road to the Chatham and Dover Railway, by clearing away the store houses, customs house, harbour master's house, and all buildings and obstructions which might interrupt the view of the mouth of the harbour and the Downs beyond.

The authorities of the adjoining town of Dover have commenced harbour works of a very extensive kind, which, when complete, will doubtless bring additional trade and prosperity to the town, and also form a very desirable place of shelter to accommodate shipping of the largest class.

The courtesy of the engineers, Messrs. Coode, Son, & Matthews, enables me to give you a complete description, part of which has from time to time been referred to by other writers. It is, however, to me an engineering work so important and interesting, that I venture to record it in fuller detail, the more so as we have, by the courtesy of the engineers, been invited to visit the works during the course of their construction.

Half a century ago a Royal Commission recommended that extensive harbour works should be undertaken. The lines then indicated, after a lapse of forty years, were confirmed by another body appointed to consider the subject. Between those dates no fewer than nine other schemes were put forward.

The national harbour then proposed, which was to have been built at the expense of the State, and extended across the entire sea front of Dover, east of the Admiralty pier, has now given place to a purely commercial undertaking promoted by the Dover harbour authority, who obtained the necessary parliamentary powers—readily granted—authorising the Dover Harbour Board to defray the cost by imposing a tax of one shilling per head on every passenger embarking or disembarking at the port. Even on the basis of the present revenue, this impost will yield an annual return of at least 16,000*l.*

The work commenced with the formation of an inclined road or approach from the front of the esplanade, a little to the east of the Granville Clocktower, which is to be taken down and rebuilt. This approach consists of thick walls of concrete

faced with granite. The roadway and footpath will be protected by an exterior coating of asphalt, the walls resting upon concrete cylinders sunk to the chalk and filled solid. Starting from the sea abutment of this approach, there will be an open iron viaduct, 1260 feet long, arranged in bays of iron piles 40 feet apart, stiffened at three points laterally by braced piers, so as to give due rigidity to the work. Each of the ordinary bays will rest upon three piles; but the braced piers will have five piles. The level of the deck of the viaduct will be 19 feet above high water spring tides, so as to lift it above the reach of the sea during the heaviest gales. The viaduct will have an uniform width of 30 feet throughout its entire length, there being two side paths, each 6 feet wide, and a central roadway 18 feet wide. It is proposed that the structure shall be carried on three rows of latticed girders, supported by wrought-iron piles securely braced together; the piles being in all cases driven deep into the chalk and filled in with concrete. Along the shore there is a considerable deposit of sand and fine gravel, reaching a depth of 20 feet, and gradually tapering away towards deep water. The piers nearest the shore will penetrate this bed of sand and gravel, and rest in the chalk, while the piers supporting the outer section of the viaduct will be driven into the bare chalk. On the girders a roadway will be formed of corrugated plating three-eighths of an inch, riveted together, so as to form a continuous table from one end to the other. The corrugations will be filled in with concrete, and on this paving blocks of jarrah timber will be laid. The footpaths consist of Portland cement concrete laid upon the ironwork, with French asphalt surfaces. Iron is to be used for the mouldings, curves, and gutters; and a neat handrail will be erected at each side of the pier. At the three points chosen for the stiffening bays, open iron seats will be provided; while in the middle bays there will on each side be a covered screen 100 feet long, capable of affording shelter to a large number of persons. Between these bays the width over all will be 52 feet, the side structures causing no interruption in the promenading space of the pier.

The viaduct will be followed by a solid pier, 1500 feet long, consisting of concrete blocks ranging from 12 to 20 tons in weight. Above low water mark these blocks will be faced with granite; and in all cases they will be founded on the chalk, excavated to a depth of about 3 feet, and levelled off to provide a secure foundation. The top width of this portion of the eastern arm will be 35 feet, and the bottom width, resting in the chalk, 45 feet; the whole of the blocks being bonded and joggled together, so that the work will be practically mono-

lithic. It is arranged that the coping level of this pier shall correspond with that of the existing Admiralty Pier, being 10 feet above high water of spring tides; the difference between the level of this portion of the work and that of the viaduct being met by an incline having an easy gradient of 1 in 40. On the seaward side there will be a parapet 10 feet wide—the top forming a promenade 6 feet wide and a shelter parapet, like that on the Admiralty Pier, 3 feet 6 inches in width, supplied with railings, stairways, and other necessary adjuncts. Above the granite-faced concrete blocks the work will be solid granite, the end of the arm being finished off by a circular head 55 feet in diameter, on which will stand a lighthouse built of the same substantial material—the blocks of the head being bonded, joggled, and cramped together. Along the back of the solid work will be laid a protective apron, consisting of two rows of concrete in bags (each weighing 14 tons), which will preserve the chalk foundation from the erosive action of the sea.

This east arm of the harbour is to take a south-easterly direction until the curve is reached, when it will tend more to the south; the outer portion being south-south-west.

The description given sketches shortly the plan proposed for the first portion of the scheme now in progress. It is intended in the future to extend the present Admiralty Pier a distance of 580 feet, forming, with the head of the east pier just described, an opening to the new harbour 450 feet in width. This can be modified by carrying on the works further, which will doubtless be done in the way that experience may show to be desirable. The construction of the Admiralty Pier has already occupied thirty years, and cost over a million sterling.

As soon as the works afford sufficient shelter within the harbour, the reclamation of a shallow water area five acres in extent, situate in front of the Lord Warden Hotel, will be proceeded with. Hereon two jetties will be constructed, each 400 feet in length and 100 feet wide. They will be furnished with capacious landing stages, which will enable vessels arriving at the period of low water to discharge their passengers at a low level. The total quantity of concrete to be used on the works will be 310,000 cubic yards. The granite used will equal 460,000 cubic feet, and the iron for the viaduct will weigh 3000 tons.

Mr. John Jackson has contracted to carry out part of this work, at a cost of 414,000*l.*, and has also undertaken to complete the same within six years. After this there remain to be completed the Admiralty Pier extension, the internal jetties, the sea wall, and the reclamation of the shallow water area, five acres in extent.

Noticing the work of the Society for the past year, it is a matter for congratulation that the papers contributed to the 'Transactions' were instructive in the best sense of the word, an interesting discussion following the delivery of each. The subjects embraced "Electricity as a Motive Power applied to Traction and Hoisting Machinery," "Dry Crushing Machinery," "Sewage Precipitation Works," "The Cleansing and Ventilation of Sewer Pipes," "On the Use of Steel Needles in Tunnel Driving," and "On the Shortlands and Nunhead Railway." The latter we had an opportunity of inspecting last year during its construction. It is needless to more than refer to the titles of the papers, which are recorded principally to indicate the varied and useful class of subjects discussed during the year, which should be sufficient inducement to attract to the Society members from every department of civil and mechanical engineering. While it is gratifying to find that for 1892 the Society increased in numbers, let me impress upon you all the advantage we gain from these increased numbers, and urge you to use personal efforts to introduce all those from among your friends who are qualified to join the Society.

My remarks will be closed by a few words offered to the younger members, on whom we depend as our followers in the application and development of the principles of engineering science. They are suggested by a review of the instructive visits made by the Society last year. The especial design of the Society has been to add to the better practical education of the younger members of the profession by arranging visits to harbours, dockyards, bridges in course of construction, and locomotive works—indeed, the Council take advantage of all opportunities which enable them to offer to the members practical information and instruction.

It is true that careful preparation is necessary by all those who seek to follow the profession of an engineer; but it must be combined with sound practical knowledge, gained by observation and experience from the achievements of others. Sound education is absolutely necessary to secure success; hence the obligation of strict attention to rudiments and first principles during the period of training. To be well acquainted with the elementary part of a subject is to lay the sure foundation on which after experience may be safely built; and frequent recurrence to first principles will save many weary hours of useless study. Let me therefore repeat, Be careful to be well acquainted with the rudimentary part of your profession, which, if followed by close observation and good judgment, will bring its own reward.

Experience most firmly proves that scientific research, and the result of that research developed in practice, should be kept entirely distinct. There is, however, no good reason why practical men should not become more scientific, and scientific men more practical. A recent writer says, "Those who maintain that the human intellect is still growing, point to the progress made by science during the last 2000 years, and ask, Could such progress have been made unless there had also been an immense development of brain power?" In my opinion, the answer is, that it is not by the possession of finer brains that successive generations of men of science have made greater discoveries, but by the help afforded by the accumulation of experience which one generation leaves to another to work upon—enabling their successors, without one whit more brain-development, to further advance along the road of progress. It is not required that the generation which comes to the task to-day should possess a larger and better brain power than the past generation; the advantage lies in the inheritance of the experience acquired from those who have gone before.

Further illustration cannot be wanted to press home the importance of the existence of a Society like this, which combines practical instruction with interchange of experience as the only means by which men of observation can become useful or great.

A book was put into my hands a few days since, published by Messrs. Cassell & Co., entitled 'A Successful Life.' The writer is anonymous, and calls himself "An Elder Brother." Few elder brethren could give better advice; and the book should be in the hands of every young man, especially those preparing for a professional career.

And now, gentlemen, although there is much more one would like to say to you, it must be reserved for a future occasion, and a conclusion made by heartily and sincerely thanking you for the honour you have conferred upon me in electing me your President, which is fully recognised as the highest honour you can bestow on any of your members; and, in return, let me assure you that the continued prosperity of the Society during my year of office shall be my anxious care.

March 6th, 1893.

WILLIAM A. McINTOSH VALON, President, in the Chair.

THE LEICESTER MAIN DRAINAGE, AND THE CONSTRUCTION AND TESTING OF THE SEWAGE PUMPING ENGINES AND BOILERS.

By E. G. Mawbey.

For many years Leicester has been one of the most prosperous towns in the country. The population at the Census of 1861 was 68,052; at the Census of 1881, 122,351; and at the Census of 1891, 142,051, the area of the borough being then 3030½ acres. In the year 1891 the Corporation obtained an Act of Parliament for very extensive additions to the borough, for which scheme the author was the engineer. The area was increased to 8534½ acres, and the population is now about 180,000. The rate of increase within the area of the extended borough has for the last seven years been about 3 per cent. (compound) per annum. The rateable value is now about 650,000*l.* Both the gas-works and the water-works are the property of the Corporation. Mr. Alfred Colson, M. Inst. C.E., is the gas engineer, and Mr. F. Griffith, M. Inst. C.E., is the water engineer. The Corporation have for several years past been carrying out very extensive special engineering works for the prevention of floods; the interception and disposal of sewage, and for carrying off storm waters. In former years those parts of the town adjacent to the river Soar frequently suffered enormously from floods after excessive rains, and owing to the invert of the outfall sewer being about 8 feet below the normal level of the river, the sewers were often seriously back-watered, and the cellars flooded when the old sewage pumping engines were overpowered and the river swollen. The old sewage precipitation works designed about forty years ago by Wicksteed, when the population was only about 60,000, being inadequate for nearly three times that population, the river receiving the effluent had of late years become badly polluted.

The new floods prevention works, within the limits of the

old borough boundaries, are now finished, and they have cost 352,000*l.*, which, however, includes surplus land acquired of the value of 44,500*l.* The drainage area of the river above Leicester is 147 square miles. The new flood channel will carry off 400,000 cubic feet of water per minute, or $1\frac{2}{3}$ inches of rainfall in 24 hours, and the length of the weirage is 500 feet. These works were for the most part designed and carried out by the late Mr. Joseph Gordon, M. Inst. C.E., and Mr. F. Griffith, M. Inst. C.E., and were completed, and the new west bridge designed by the author as successor to Mr. Gordon, when that gentleman was appointed chief engineer to the London County Council. The flooding has been most successfully prevented within the original boundaries of the borough, but the river improvement will probably have eventually to be extended through the newly added areas of the borough, which will be another heavy undertaking.

The storm outfall works, designed by the author, are now being carried out, the contracts let amounting to 71,447*l.* The main culvert is 8 feet in diameter, and is intended for carrying off the storm waters from the sewers during heavy rains from the sewage pumping station, to a point in the river Soar, about $3\frac{3}{4}$ miles down the valley, where a free outfall by gravitation for the sewers in the borough can be obtained, thus preventing the back-watering and cellar flooding before referred to. This culvert will discharge about 70 million gallons per 24 hours, or the whole of a rainfall of about $1\frac{1}{2}$ inches in 24 hours from the present built area of the extended borough. This provides for a maximum rainfall of about 3 inches in 24 hours on the present built area, as only about half the rainfall reaches the sewers. In case of exceptionally heavy rains and thunderstorms of short duration, when the rate of rainfall is greater than this storm outfall culvert will carry off, the sewers of the town are relieved by storm outlets into the river and a canal within the borough which will carry off nearly a quarter of an inch of rainfall per hour. The 10 miles of new main intercepting brick sewers and storm outlets in the borough were designed by Mr. Gordon, and will, when completed, have cost about 105,000*l.* The two main trunk sewers are 7 feet 3 inches by 6 feet 3 inches, and 5 feet 3 inches by 3 feet 6 inches respectively. Nearly a third of these works were executed under Mr. Gordon's personal direction, and the carrying out of the remainder, and the preparation of the working drawings for rather more than half of these works have devolved upon the author acting as the chief engineer. A further sum of 13,400*l.* has recently been sanctioned for additional sewerage in the added areas, designed and now about to be carried out by him.

The main intercepting sewers will carry off to the main storm outfall culverts a volume equal to a rainfall of about $1\frac{1}{2}$ inches in 24 hours from the present built area of the extended borough, and will carry to the several storm outlets in the borough, volumes nearly equal to a rainfall of a quarter of an inch an hour, thus really providing, as before explained, for about double these rainfalls on the 1925 acres of area now built upon, and for rainfalls of $1\frac{1}{2}$ inches in 24 hours, and a quarter of an inch per hour respectively, when the present built areas and the population have been doubled. The sewers are all constructed of brickwork, built in Portland cement mortar. The separate system of main sewerage has not yet been carried out in the old streets to a very large extent, but separate surface water sewers are laid in all new streets with a view of extending this system eventually. Flushing gates at distances from 250 to 300 yards apart are provided on the new main sewers, by which the sewage is dammed up for short periods until it reaches the springing of the arch of the sewer, when it is let off suddenly. The various important works designed by the late Mr. Gordon will be a lasting testimony to that gentleman's exceptional engineering ability.

Pumping Station and Sewage Farm.

The sewage flows into a screen chamber, passes through a coarse screen sufficient to intercept any large substances, and then through a double set of fine screens arranged so that one set can be lifted and cleansed whilst the others are in work. Thence it flows into a middle reception chamber, and on through penstocks into two separate pump-wells. The sewage is forced from the pumping station through two 33-inch rising mains, for a distance of about a mile and a half into the distribution tanks at the sewage farm, to a net height of about 163·66 feet above the invert of the outfall sewer at the pump wells. The dry weather flow of sewage is about $6\frac{1}{2}$ million gallons per diem. The total area of the sewage farm is 1700 acres, of which about 1400 acres will be available for sewaging.

The carriers, main effluent culverts and roads for about 850 acres were designed and largely carried out by Mr. Gordon. The designing and carrying out of the remainder of such works, and also of the preparation of the land for sewage treatment have been done by the author, and on different principles to those originally intended. The total expenditure sanctioned for the works upon the farm up to the present time is 58,900*l*., and these works will shortly be completed—100 acres of this

land were purchased by the Corporation for 13,000*l*., the remainder is leased at 45*s*. an acre. The system is broad irrigation, but owing to the impervious clayey nature of the soil, preliminary chemical treatment will probably be eventually resorted to before application to the land. The sewage has, however, up to the present time, been satisfactorily purified, and the long standing pollution of the river entirely abated.

Engines, Pumps and Boilers.

There are four engines of the independent rotative compound condensing beam type. The diameter of the high-pressure cylinder is 30 inches, with a stroke of 5 feet 9¼ inches, and that of the low-pressure cylinder 48 inches, with a stroke of 8 feet 6 inches. The cylinders are steam jacketed, that of the high-pressure cylinder being fed with steam at the boiler pressure of about 80 lb. to the square inch, and that of the low-pressure cylinder at the pressure at which the steam leaves the high-pressure cylinder. The steam cylinder pistons are of the Mather and Platt type, each piston being fitted with their patent steel springs. The steam cylinder valves are of the double-piston type, arranged in a cylindrical casing, cast separately from the cylinder, through which the admission and escaping steam for both high and low pressure cylinders passes. The high-pressure steam cylinders are fitted with expansion piston valves, designed and arranged to cut off the steam at any point from $\frac{3}{4}$ to $\frac{1}{8}$ of the stroke, by means of hand gear which can be worked whilst the engines are running, the working rate of the expansion being clearly indicated by automatic arrangements of pointers and scales.

The low-pressure cylinders are also fitted with expansion piston valves, designed and arranged to allow of the cut-off being varied between $\frac{1}{4}$ and $\frac{1}{2}$, the working point being automatically indicated, as in the case of the high-pressure cylinders. The double piston valves are actuated by eccentrics, keyed to horizontal weigh-shafts below the engine-room floor, to which motion is transmitted by wheel-gearing from the crank shaft.

To each engine there are two main pumps for the sewage, of the piston-and-plunger type, one at each end of the beam, having a stroke of 5 feet 9¼ inches, the diameter of the piston being 27¼ inches. The suction and delivery valves are of the flap type faced with india-rubber, and the hinges bushed with gun-metal. They are arranged with large waterways to minimise the friction by the sewage passing through, and to prevent

mishaps through the lodging of extraneous matter. The two main suction pipes are 3 feet in diameter, leading from the pump well and screen chamber to each pair of engines. A steel air vessel 25 feet 9 inches high by 5 feet diameter is fixed to each rising main. The air pumps and condensers are of the single-acting jet type, the whole of the internal valves and fitings being of gun-metal, with flat india-rubber discs.

The fly-wheels are of cast iron, 21 feet in diameter; they weigh about 21 tons each, and are cast in segments, planed and bolted together. The beams are formed of double steel flitches 2 inches in thickness and 6 feet in depth at the centre. Each complete beam weighs about 15 tons. The main centre gudgeons of these beams work in massive plummer-blocks with hard gun-metal bearings, secured and fixed to the entablature by turned steel bolts and cotters, and anchored down into the foundation. The entablature consists of moulded cast-iron girders, seated upon ornamental cast-iron columns. All the gauges for Nos. 1 and 2 engines are grouped together on a stand. There is also an automatic counter recorder for each engine, which shows upon a diagram the number of revolutions for any period. The gauges and recorder for Nos. 3 and 4 engines are in a similar group. There is an electric float recorder fixed in the author's office at the Town Hall, about a mile and a half distant, which indicates upon a diagram the level at which the sewage is kept pumped down to in the sump. An alarm gong is fixed to the sewage pump relief valves.

There are eight double-flued Lancashire steel boilers, each 30 feet in length and 7 feet in diameter, fitted with seven conical cross tubes in each flue, and designed for a working pressure of 80 lb. to the square inch. The feed water to the boilers is supplied by two double-acting donkey pumps. An overhead traveller, constructed to lift 18 tons suspended in the centre, is provided. The span from centre to centre of rails is 45 feet. The workshops are very complete, and are fitted with engine power and modern machinery for the necessary repairs.

Cost of Pumping Station, exclusive of Land.

	£
Main building, engine foundations, coal store and chimney ..	13,667
Engines, boilers, &c.	25,286
Workshops and machinery	1,656
Manager's house	739
Fence walls and drainage	700
1½ miles (about) of double line of 33 in. rising main to sewage farm	12,922
	£54,970

The total cost of carrying out the schemes mentioned will be nearly two-thirds of a million sterling, exclusive of the works of the gas and water departments.

Description of Trials and Methods adopted.

These trials were not confined to simply ascertaining whether these engines and boilers would or would not perform the work required by the specifications, but were carried out in a somewhat exhaustive and detailed manner. The trials proper extended over eight days. The staff did not leave their posts for many minutes together. Refreshments were provided on the spot. To change the staff in shifts was considered unadvisable. Each of the four engines was first separately tested twice to ascertain the net quantity of sewage they would deliver per revolution and per hour into the tanks at the sewage farm, as measured by the capacity of these tanks, which were constructed mainly for this purpose. Each of the three tanks contains about the quantity pumped by one engine in an hour. They were also tested for the same purpose whilst working in pairs, Nos. 1 and 2 engines twice, and Nos. 3 and 4 engines three times over. This was worked by telephonic signals between the pumping station and the farm, given at the moments of commencing and finishing of the filling of each tank, at which moments the readings of the counters for the numbers of revolutions, and also the times, were taken and recorded. The tanks were emptied from time to time by a portable steam chain pump.

In addition to these tests, in order to check the quantity of sewage pumped on to the farm, it was discharged over weirs at the farm tanks and gauged day and night about every ten minutes during most of the pumping operations of the trials. Besides the partial tests for the special purposes already named, all the engines were fully tested as follows:—

Nos. 1 and 2 engines working together with steam generated by Nos. 2, 3 and 4 boilers were fully tested for $12\frac{1}{4}$ consecutive hours. These same engines and boilers were again tested $12\frac{1}{10}$ consecutive hours, from 10 A.M. to 10.6 P.M.

Nos. 3 and 4 engines working together with steam generated by Nos. 5, 6 and 7 boilers were fully tested for 24 consecutive hours, commencing at 12 o'clock at night. Under the author's direction, and the strictest supervision, the maker's own men acted as engine drivers and stokers. A member of the maker's firm was present during most of the time the actual trials were proceeding, and his foreman and two assistants were present

the whole time, and were allowed to witness and note our observations as far as they were able to do so, but during the trials no unnecessary conversation was allowed, and all interference was strictly prohibited. Throughout the trials, in addition to the constant measuring of the sewage over the weirs at the farm, the following operations were repeated at least once an hour, and during part of the time twice an hour, and observations taken and noted on the printed forms specially prepared for the purpose:—namely, the reading of the barometer; the reading of the steam gauges on the boilers; the reading of the initial steam gauges on the engines. The readings of the thermometer for the temperatures of the external air, the boiler room, the water in the hot wells of the engines, the feed water, the injection water, the water discharged from the condensers, and the readings of the pyrometer for the temperature of the escaping gases in the flues. Each trial was commenced and finished with uniformly level and bright fires of certain measured thicknesses, which were chalked upon the furnace doors. At the commencement of each hour a certain quantity of coal was weighed out in bags and delivered into the boiler house by the author's assistants and stokers. The coal heap and the coal in the boiler house were never left unwatched. The time of commencement to use each lot of coal was recorded, and also the time at which each fire and each boiler was made up. At the close of the trials any remaining coal was weighed off and deducted. The ashes were also weighed, to ascertain the net amount of combustible in the coal, but were not deducted in determining the duty of the engines. The level of the feed water in each boiler at the commencement of the trial was noted, and was brought to the same level at the finish. The feed water was at each hour measured by a Kennedy positive meter. The accuracy of this meter has been verified by pumping through it into a tank. The water discharged per hour by the air pumps from the condensers was regularly gauged, flowing over a thin plate notched weir, and this discharge was also frequently tested by measuring into a cylindrical tank formed by a line of 33-inch cast-iron pipes, jointed together for the purpose, and having a total capacity of 2798 gallons. The temperature and quantity of condense water from the low-pressure jackets of the engines were regularly observed. Also at the same intervals, hourly part of the time, and half-hourly during the remainder of the time, four indicator diagrams were taken of each engine alternately. The reading of the engine counters for the number of revolutions was also worked off. The readings of the pressure gauges to give the load of sewage upon the engines, and the height of the sewage in the pump

well, were also recorded. The average reading of the points of cut-off of steam was as follows:—

	Trial No. 1.		Trial No. 2.		Trial No. 3.	
	Engine No. 1.	Engine No. 2.	Engine No. 1.	Engine No. 2.	Engine No. 3.	Engine No. 4.
Cut-off in high-pressure cylinder	·29	·37	·29	·35	·32	·32
Ditto in low-pressure cylinder	·29	·37	·29	·35	·32	·32

The engines throughout the trial were regulated by the high-pressure cut-off gearing alone, the steam stop valve being always kept full open, the low-pressure cut-off remaining constant. Each of the sewage pumps was stethoscoped at short intervals to ascertain the behaviour of the valves within, particularly as to whether there was any slip caused by extraneous matter getting under the valves. The engines were worked all through as near as possible at twelve revolutions per minute, and with a boiler pressure of about 80 lb. to the square inch. The steam used for the donkey feed pumps was taken from a separate boiler, supplied with coal apart from that used for the pumping engines, the pressure in this boiler being kept at least 20 lb. below the pressure of the others. The coal required for the donkey pumps has, by a separate test, been found to be only 2·38 per cent. of the whole quantity used, or only 0·05 lb. per actual horse-power in water lifted.

The temperature of the escaping gases in the flues, &c., kept very low, showing abundance of heating surface, efficiency in absorption of heat by the boilers, and the advantage of the slow firing which was adopted. The whole of the steam pipes in the boiler house and engine house, and all the boilers, are covered with Bell's asbestos. The cylinders and steam receiver chambers and valve chambers are lagged. During the trials the flanged expansion joints to the steam pipes and also the cylinder tops were temporarily covered either with old sacking or felt, and the doors and windows of the engine and boiler houses were kept closed. The weather was fine and warm in the daytime during the tests, and there was hardly any wind, which in respect to temperature and calmness was somewhat in favour of the economical working of the engines and boilers.

The question was raised as to whether the makers, Messrs. Gimson & Co., were entitled to temporarily cover up the parts mentioned. The author decided that, having regard to the very little benefit to be derived from the temporary

covering of the very limited surfaces which are not permanently covered with asbestos or lagging, not to object to it, nor to the closing up of the doors and windows of the engine and boiler houses, as these were legitimate means of economy, which could always be adopted. Whilst the makers were allowed to work their engines to the best advantage, the author in calculating the quantity of sewage lifted, allowed less rather than more for the work actually done.

The engine house at Beaumont Leys pumping station is illustrated at Fig. 1, and the engines at Figs. 2 and 3, the indicator diagrams being shown at Figs. 4 and 5.

Results of the Trials.

The detailed results obtained by the working out of all these observations are given in the table appended to the paper, but the result of these trials in the main compared with the chief terms of the specification are as follows:—

The specification required that each engine should be run at a uniform speed of twelve revolutions per minute, and should force and deliver into the distribution tanks at the Beaumont Leys farm the sewage at the rate of 200,000 gallons per hour; and that the quantity should be measured by the capacity of the distribution tanks. The minimum quantity delivered by any one engine, separately tested according to the specification, and as previously described, was at the rate of 205,920 gallons per hour (or 286 gallons per revolution) at twelve revolutions per minute, or about 3 per cent. more than specified. The mean quantity of all the eight separate tests of the engines was at the rate of 208,480 gallons per hour (or 288·33 gallons per revolution), at twelve revolutions per minute, or about 4 per cent. more than specified.

In the five tests of the engines, working together in pairs, and pumping into the tanks during the complete trials of the engine and boilers, both the minimum and the mean quantity delivered were at a greater rate per engine per hour than was performed when each engine was separately tested, and this is borne out by the gauging over the weirs at the tanks. But to be on the safe side, as there was some little difficulty in gauging when the two engines were worked, the author adopted the lesser mean of 288·33 gallons of sewage delivered per revolution, on which to base the most important of all the calculations, viz. the actual quantity of sewage pumped to the highest point on the farm, by the consumption of a given quantity of coal. There was very little slip through the valves or pistons of the

pumps; in Nos. 1 and 2 engines only about 1·27 per cent., and in Nos. 3 and 4 engines only about 0·87 per cent., and scarcely any leakage from the pump stuffing boxes.

The specification also provided that the engines and boilers together should not consume more than $2\frac{1}{2}$ lb. of coal per actual horse-power per hour in water lifted. Nixon's navigation coal was used, the dust and small stuff being taken out by a 1-inch mesh riddle before weighing. Based upon the before-mentioned lowest mean quantity of sewage pumped, Nos. 1 and 2 engines in the first $12\frac{1}{4}$ hours' complete trial consumed only 1·97 lb. of coal per actual horse-power per hour in sewage lifted, and in the second trial of $12\frac{1}{10}$ hours' duration, only 1·95 lb., the mean of these being 1·96 lb., or 21·6 per cent. less than specified. On the same basis Nos. 3 and 4 engines, in the 24 hours' complete trial, consumed only 1·82 lb. of coal per actual horse-power per hour in sewage lifted, or 27·2 per cent. less than specified, showing the advantage of the longer trial. The duty (measured by the weight of water actually pumped whilst running at a speed of twelve revolutions per minute, and with a boiler pressure of 80 lb. per square inch) was specified to be not less than 100 million foot-pounds per 112 lb. of coal.

The trials were in compliance with these terms, and on the same basis as the preceding results, the duty of Nos. 1 and 2 engines in the first $12\frac{1}{4}$ hours' trial was 112·483 million foot-pounds, or 12·48 per cent. more than specified; and in the second trial of $12\frac{1}{10}$ hours 113·765 million foot-pounds, or 13·76 per cent. more than specified, and the duty of Nos. 3 and 4 engines in the 24 hours' trial was 121·492 million foot-pounds or 21·49 per cent. more than specified. All the four engines, after being fairly started, worked freely and briskly with remarkable smoothness and evenness of motion, with very little concussion at the commencement of the stroke, and with an entire absence of undue vibration either of the machinery or of the building, and none of the crank-pins, gudgeons or other working parts became hot during the trials.

It will be seen that the averages in the table giving the results of the trials are taken from the three trials, no note being taken that No. 3 was of twice the duration of Nos. 1 and 2. If the duties of the two pairs of engines were averaged, the mean trials of Nos. 1 and 2 must first be obtained, and the resultant compared with trial No. 3. The figures thus obtained would differ slightly from those printed in the column of averages.

The engines and boilers in the main were originally designed by the late Mr. Joseph Gordon, C.E., assisted by Mr. T. E. Laing, C.E., but the detailed drawings were subsequently more

or less revised and improved by the late Mr. Gordon, in consultation with the engineering inspector, Mr. G. L. Lambert, and the makers, Messrs. Gimson & Co., of Leicester, and some further improvements were introduced by the author. The buildings were designed by Mr. Stockdale Harrison, F.R.I.B.A., of Leicester. The work was well in hand before the late Mr. Gordon left Leicester and the main details had been settled by him, but the greater part of the manufacture of the engines and boilers, the fitting up in the shops and the erection were done under the author's personal supervision as successor to Mr. Gordon. In this testing work the author was assisted by members of his office staff, whom he thoroughly instructed and practised together in the several operations previous to the official trials.

DISCUSSION.

The President said he was sure they would all unite in passing a very cordial vote of thanks to Mr. Mawbey for his paper. The details were very elaborate, and the working out of the whole paper had been very creditable.

The vote of thanks was accorded by acclamation.

Mr. G. A. Goodwin said they must all feel very much obliged to the author for having brought this interesting paper before them. It did not fall to the lot of every engineer to have the opportunity of carrying out such comprehensive tests as he had done, the record of which would be a great acquisition to the Transactions of the Society. The author had stated that the cut-off of the steam could be regulated from five-eighths to one-fourth of the stroke, but the printed copy of the paper, which had been supplied to Members, stated three-fourths to one-eighth. He should like to know which was to be taken as correct. He would point out that a vacuum vessel should have been provided on the suction pipe, so that there would always be a head of sewage ready to flow into the pumps without being drawn in. Thus, when the pumps began to draw they would not have to set in movement all the mass of sewage behind them, as it would flow down from the vacuum vessel into the barrel, and filling up again gradually, while the pumps were making the down strokes. He would suggest that it would be advisable in the case of sewage pumps, though, perhaps, expensive, to coat the barrels with copper. The copper could be electrically deposited, and a very good result would be obtained, as the coating would prevent the sticking together of the plunger and the gland. In describing the engine, the author

said that there was a quarter of an inch lead, but he (Mr. Goodwin) really thought that that must be a mistake, unless the author meant that the port began to open when the piston had travelled to within $\frac{1}{4}$ inch of the end of its stroke. He (Mr. Goodwin) was not sure that the method of exhausting the steam from the high-pressure cylinder all round the central valve was a good one, for the exhaust steam, after it had done its work, was relatively cool, and would cool the live steam inside, which of course should be kept as hot as possible. With regard to the piston valves, had they rings in them, and if so, how were the rings prevented from springing into the ports when they passed over them? He should imagine that the ports had bars placed across diagonally, so that as the valve passed over them they would give a uniform wear, and at the same time prevent the rings from slipping out and catching. Again, when the engines were worked simultaneously, was any provision made for coupling them together, so that they should work in proper period, that is to say, at right angles to one another, in order that the two engines might not be pumping the sewage and delivering it into the mains at the same moment? With reference to the boilers, the author did not state one way or the other whether they were fitted with combustion chambers. It was a very good plan to have two flues joined together at the back end of the boiler into one large chamber, in which there were also water tubes. It allowed a much better combustion, because one furnace could be charged while the other one was at its maximum intensity, so that the gases from the one newly charged were burnt up by the flame from the other furnace. He would like to know whether the rising mains to the sewage farm were of cast iron or wrought iron.

As to the test, it seemed to him that it would have been better to have commenced at 12 o'clock at noon, rather than at 12 o'clock at night, so as to have had as much daylight as possible. Later on, the author stated that the reading of the pressure gauges gave the load of sewage, but in the printed list giving the results of the trial, it was stated in the fifth item from the bottom, "Head of sewage or load on engine, including friction taken from pressure gauges, &c." He should like to know what the author meant by friction, and how he was enabled to determine the friction from the pressure gauge. The following paragraph appeared in the paper: "The engines throughout the trial were regulated by the high pressure cut-off gearing alone, the steam stop-valve being always kept full open, the low pressure cut-off remaining constant." If the low pressure cut-off remained constant, how was it that, in the table which the author gave, the low-pressure cut-off agreed with the

high-pressure? If he altered the high-pressure, it would also appear that he altered the low-pressure, for in every case they were identical. Then again, the author had stated that, in calculating the quantity of sewage delivered by the engines, he had taken the lesser mean rather than the work actually done. He (Mr. Goodwin) wished to ask why the exact amount was not taken, as he maintained that it ought to have been, and why did the author detract from the duty of the engine, giving himself the advantage, instead of the manufacturers? Again, the author had stated that the number of gallons delivered per revolution was 286, but from the figures which he had given, he (Mr. Goodwin) made it out only as 228. He wished the author to reconcile that. Could the author also give any reason why, when the engines were running together, coupled up, he got more duty in the way of sewage pumped, than twice the quantity delivered by one engine working separately? In his opinion it was due to the sewage running more evenly, and in a more continuous flow, one engine, as it were, helping the other, or, rather, that no obstruction was caused in the form of dead or intermittently flowing matter to be pumped against. Once or twice in the paper the author used the word "water." He presumed that he meant sewage in every case. He would suggest that it would have been much better to have put the air vessel on the top of the valve chamber immediately above the delivery valves. That arrangement would allow a much better action for the air vessel, for instead of having the water flowing up and down in it, owing to fluctuations of pressure, at right angles to the direction of the flow in the mains, it would simply rise up and down in the direction of flow, and he had no doubt that it would give a better result in the pumping. The author had stated that there were slight shocks on the pumps, and he (Mr. Goodwin) was inclined to think that they would be prevented by putting the air vessels in the position he had indicated. Possibly the great lead on the steam valves was advisedly given to mitigate the flow of the water in the pumps. He would also ask the author how it was that he got such a very low temperature at the foot of the chimney. He (Mr. Goodwin) had never known any boiler setting to give less than about 400, but the author had given as low a temperature as 319 degrees, and lastly, even with this low temperature, would it not have been an advantage to have had an economiser? for, although the feed water was 97°, there would still have been some advantage to be gained by its use.

Mr. Henry Law said, the general arrangement of the engine had been very carefully considered, and well thought out. In his own experience, he always liked to have the

longest stroke he could, in comparison with the diameter of the pump. He liked to have the suction and delivery pipe at least as large as the working barrel; and he entirely concurred with Mr. Goodwin as to the desirability of putting an air vessel on the suction as well as on the delivery pipe. In fact, he never made or designed a pump, without having an air vessel on the suction pipe. He knew of one instance in which there was a long suction pipe, and the engines were severely tried and injured, in consequence of the concussion arising from the stopping and starting, some twenty times in a minute, of a column of water of several tons weight in the suction pipe. The air vessels should always be put as close as possible to the valves; and, therefore, he should think that a very desirable place would be over the valve. The position of the air vessel in the present instance was not shown in the diagram. He did not quite know the arrangement by which access was obtained to the valve, whether it was necessary to remove the cover. There was also another important point, which was, the limit of the rise of the valve. The flap valve was a very good form of valve, but it was important that the extent to which it could rise should be limited. In working with sewage he preferred a plunger pump alone to the plunger and piston, because then there was only the packing of the gland to attend to, and that was easily got at. If the sewage was gritty, they would not get the wear of the barrel, but only the wear of the plunger.

Mr. Frank Baker said he had had the honour of being assistant to Mr. Gordon in carrying out and perfecting his schemes. He found that the author of the paper had deviated entirely from one of the most crucial points in the storm outfall sewers. He should like to ask him if he would kindly say why he had taken that course. The scheme was thoroughly considered during a great number of years by their late distinguished friend Mr. Gordon, who gave a great deal of his time to perfecting it, and whose name was thoroughly well known.

When the scheme was first entertained the idea of the borough extension was looming in the distance, and, of course, was considered, and in calculating the capacity of these sewers, ample provision was made for taking in the large extended area. It was practically the same, or as nearly as could be the same as the original scheme laid down by Mr. Gordon in 1881, and in the laying out of the scheme of course the main storm outfall sewers were designed for the purpose of carrying off the storm water from that enormous area. The whole of Leicester was on the east side of the river. There were practically few houses or buildings of any account on the other side. Therefore Mr. Gordon's scheme was to take the main outfall sewer from

the Belgrave Road in twin culverts 8 feet diameter each straight down the Melton Road; there was also an additional culvert for the east side of the river 7 feet 6 inches by 5 feet 6 inches. He would be glad if Mr. Mawbey would kindly describe the arrangement of the outfall that he had altered, for he had himself been engaged for some time in surveying the district for those very storm outfalls. He thought that it was well known amongst engineers that the rainfall all over the area should be carefully gone into, and calculations very carefully made.

After referring to the main intercepting sewers the paper went on: "The various important works designed by the late Mr. Gordon will be a lasting testimony to that gentleman's exceptional engineering ability," with which expression he entirely concurred.

Mr. W. Santo Crimp said that the author entered very largely into the question of rainfall, but there was an important missing detail. One of the principal functions of a system of sewerage was to carry off the sewage to the outfalls, and he would ask the author what proportion of the sewage proper was discharged at the purification works, and what proportion escaped by means of the storm outlets into the river? He had recently had to closely examine the working of the London main drainage system from that point of view, and he might say that he was surprised at the results which he had met with. Judging from those results and from the details given by the author, he thought it would be found that something like 97 per cent. of the sewage would be carried to the disposal works, and that only about 3 per cent. would escape by means of the storm overflows. If he was right in his view of the matter, the author ought to be very careful how he expended money in extending the separate system. With regard to land treatment he remembered that he had had the pleasure of meeting Mr. Mawbey at Wimbledon four years ago, and he then pointed out the evils they had experienced at the Wimbledon sewage farm—which was mainly of clay—by reason of the underdrains, which, in dry weather, when the soil cracked, admitted the sewage, which was discharged from them in an unpurified condition. Many of the drains were therefore removed, and he presumed the special treatment of the Leicester farm referred to by the author was in connection with the subsoil drainage.

With regard to the pumping machinery generally, when he stated that at Abbey Mills, where they pumped something like 70 million gallons a day, they were still using steam at a pressure of only 25 lb. to the inch, those present would recognise the vast strides that had been made in pumping

machinery since that at Abbey Mills was erected, particularly in the direction of economising fuel. At Abbey Mills Pumping Station they were using about 6 lb. of rough small coal per pump-horse-power, whereas the author had got down to less than 2 lb. of Welsh. The County Council were fully alive to their responsibility in the matter, and they had already erected high-pressure boilers, and had let a contract for compounding the engines. With regard to the air vessel, it might be remembered that the air vessel at Abbey Mills and that at the Western Pumping Station were both destroyed soon after the opening of the works, and stand-pipes were substituted. He did not know that a satisfactory explanation of the disasters had been given, nor could he give one, but perhaps the following facts had some bearing upon the subject. Recently the large delivery main at Abbey Mills broke across, owing to a settlement in the soil. They had to stop pumping and go inside the delivery main and repair it with steel plates, when they discovered that the stand-pipes were absolutely blocked with an accumulation of corks, pieces of wood and other floating bodies. These, of course, rose to the top of the water in the delivery main, and passed up into the stand-pipes. The number of corks especially was astonishing. In an air vessel, fatty and other floating matters might accumulate, and the air vessel, as an air vessel, might be destroyed altogether; and therefore it would be well if the author would examine it from time to time and provide means for preventing the possible fracture of the delivery mains.

With regard to fuel economisers, they were working at Abbey Mills with six boilers before the economiser was brought into operation, but now with that adjunct five were found to be sufficient for the work, and there was a corresponding saving of fuel. Would the author kindly state the cost of pumping per million gallons? That would be very useful and interesting information. In conclusion, he thought the paper was a very valuable one, and he was exceedingly pleased to find that the author had paid a most graceful tribute to the memory of their lamented friend, the late Mr. Gordon.

Mr. Boulnois said he could speak from personal inspection as to the manner in which the pumps were working. He could endorse the statement that they were working smoothly, quietly and evenly. Comparing these pumps with other pumps of which he had been able to obtain particulars, he found that their duty was remarkably good. He wished to say in parenthesis that he thought it would be a good plan for engineers to have, if possible, a unit of duty applicable to all classes of motors. The quantity of water evaporated per pound of coal

was of use so far as steam engines were concerned, but it was useless for gas or oil engines, electro-motors and engines other than those worked by steam. If some kind of unit could be arrived at, it would be a great advantage to all engineers. With regard to the Leicester engines he would state the duty of these pumps worked out in millions of foot-pounds per hundredweight of coal as compared with others. At Oxford, where there were pumps of a similar class, the duty worked out at only 74 millions as against Mr. Mawbey's engines, which gave over 100 millions. At Luton, where he believed the engines were of the horizontal type, the duty worked out at only 30 millions. At Abbey Mills, just mentioned by Mr. Santo Crimp, the figures worked out at only 35 millions. Therefore it would be seen that the engines which had been so severely handled by some speakers were really doing admirable work. No doubt some of the suggestions which had been made were excellent, but, generally speaking, the whole of the engine house did credit to the lamented Mr. Gordon, and, if he might say so, to his no less worthy successor, Mr. Mawbey. With regard to the growth of Leicester it was curious to note that not many years ago engines amounting in the total to (he believed) only 50 horse-power were sufficient for the whole of the sewage of Leicester, and now it was necessary to have the engines Mr. Mawbey had described.

As to the storm water, that was a question which, as Mr. Santo Crimp has pointed out, troubled all engineers, particularly municipal engineers. Only quite recently he had a case of flooding at Liverpool, and he took the precaution to ascertain what capacity was necessary for the sewage, and he found that the capacity of the sewer was twenty times larger than was necessary for the dry weather flow; but, notwithstanding that capacity, it was gorged during storms, and severe flooding took place. That gave to those who were not accustomed to deal with rain storms some idea of what such storms meant. In Liverpool they had the difficulty that, practically, every drop of rain water reached the sewers at once. The houses were, of course, slate-roofed, and the streets were paved, and, with the exception of a slight amount of evaporation, the sewers got the whole of the rainfall. He need not say how greatly he admired those complete engine trials which Mr. Mawbey had conducted. He only hoped that all engineers who had the opportunity, and who also had the purses of the ratepayers to fall back upon, would be good enough from time to time to obtain such useful information.

Mr. De Courcy Meade said he believed the soil of the sewage farm at Leicester was clay, and quite unsuited to the pur-

poses of sewage treatment. He remembered Mr. Gordon telling him some years ago that the farm selected by the Corporation was one of the worst of the eight alternative sites. It would therefore be interesting to know how such a large quantity of sewage was being treated on a farm of that kind, and whether the farm had turned out as Mr. Gordon predicted. He was glad to hear the remarks of Mr. Santo Crimp respecting storm water. He had charge of a district in which they were bound by a local Act to prevent the storm water, as far as practicable, passing into the sewers. The local authority was very conscientious, and had put duplicate sewers in every street in the district, and had also required two sets of drains to every house—one for roof and surface water, and the other for sewage. With the exception of Reading, he did not know another[1] town in which that had been done so thoroughly, and yet, notwithstanding all those precautions, they sometimes got a quantity of storm water into the sewers. That was a difficulty which most engineers had to deal with, especially in a district where the gradients varied very much, and the storm water consequently passed rapidly to the outfalls. He believed that the new storm relief sewers of Leicester would be formed at the bottom of a basin and close to the river. There was, no doubt, some difficulty in dealing with an outfall in a district of that kind; and if the outfall works now in progress were carried out successfully, a great deal of credit would be due to the author of the paper.

Mr. J. Cartwright said he had seen these works within the last few months, and could bear out all that Mr. Boulnois had said with regard to the working of the pumps and of the machinery generally, also with regard to the erection of the buildings, the construction of the sewers and the storm overflow. He ventured to say that there was no better work to be seen anywhere, and great credit was due both to Mr. Gordon and to the present engineer.

Colonel A. S. Jones said he should like to have more information with regard to the sewage farm than the paper contained. He happened to know the neighbourhood very well, having been over it a great many times. With regard to the sewage farm, he agreed that many better sites could have been selected; but, however, the thing was done, and there was an area of 1400 acres apparently available at the present moment, and that ought to be sufficient if properly managed. The author had alluded to precipitation. He trusted that before he resorted to that method he would utilise the land to the uttermost, and try by all means to ameliorate its condition. Unfortunately, the Leicester Corporation appeared only to have about 100 acres of their own. The remainder of the land was

leased. He hoped it was held on a long lease; otherwise the Corporation would be in a hole, as he had known others to be. With such magnificent engines and pumps, and a rising main costing about 60,000*l.*, it would be very unfortunate if they could not obtain an extension of their lease. During the last month or six weeks he had been engaged upon three inquiries with regard to obtaining additional land. That was rather a hopeful sign with regard to broad irrigation. It had been sat upon for many years by patentees and others interested in chemicals, but it appeared to be reviving again. Most encouraging information had been given by the agent of the Earl of Warwick, who had been in charge of the Leamington sewage farm since its commencement, more than twenty years ago, and even in these times of agricultural depression it had been making a profit. The agent in question said that, after charging the land 44*s.* an acre for rent and 11*s.* 9*d.* an acre for pumping charges, he was still able to make a profit on the land. Such a statement was very hopeful in these times, and it might make corporations less anxious than they had been as to the success of sewage farms.

Mr. I. SHONE said the important object in connection with sewage drainage works was to make drains and sewers self-cleansing and sanitary, and that was the reason that so much money was spent upon them. A great point was to get rid of the human wastes as rapidly as possible. The more rapidly that was done, the more efficacious were the sewers. He did not wish to say a word that would reflect upon the merits of the paper, but there was nothing which would give him any idea as to how the sewers would work. He had made a calculation as to the velocity at which the sewage would flow from the pumping station to the outfall, and he had arrived at the conclusion that it would only be 1½ feet per second if the sewage were pumped into the two rising mains from one of the pumping engines. That of course would make the friction very little. He was surprised to hear Mr. Santo Crimp say that he recommended engineers not to spend money upon storm overflow sewers in connection with works on the separate system. He (the speaker) had seen a remark somewhere which purported to emanate from the present engineer-in-chief for the London County Council, to the effect that the volume of the rainfall was 200 times larger than the volume of the sewage from a London house! It was impossible to construct sewers which would perform their function in the discharge of rainfall and sewage combined, and at the same time be sanitary sewers during the time that sewage only was being discharged into them. During heavy rainfalls the air that had been lodged in

the drains and sewers, perhaps for weeks, was displaced, and found its way past defective traps into the houses. In his opinion, that caused the death-rates of towns to be heavier than they could be made to be by adopting the separate system. If a system of sewerage could be established, as it can be everywhere, by which the sewers could be adjusted in size and inclination to their work, and the sewage was transported quickly to the outfall, there would be a very marked improvement in the health of the towns of this and every other country where sewerage works on the English water-carriage system were established.

Mr. W. G. Peirce asked the author whether the pump was really a bucket and plunger, as Mr. Law had stated? It appeared to him that the water did not pass through the bucket at all. A portion of the water was forced down by the ram and formed a kind of piston. On the return stroke the water above the piston was lifted up into the mains beyond the outlet or retaining valves. The bucket proper should allow the water to pass through, but so far as he could see it was really a double-acting piston pump.

Mr. Henry Law said that he ought to have used the expression "piston."

Mr. Mawbey, in replying upon the discussion, said, with regard to Mr. Goodwin's remarks, that the statement in the paper as to the cut-off being from three-fourths to one-eighth of the stroke was quite correct. The question of having a vacuum vessel on the suction pipe had been carefully considered. At first there had been, as Mr. Goodwin had said, a good deal of concussion. The difficulty occurred just when the engines were being started, and it was quite got over by means of pipes forming a communication between the top and bottom pump valve boxes. By that means the pumps and valve boxes were charged solid before starting the engines. He quite agreed that a vacuum vessel would have been a good thing. The coating of the barrels with copper was a good idea, but it was astonishing how little they had scored in working. With regard to the $\frac{1}{4}$ inch lead, he had taken the precaution to go very carefully into that matter. The high-pressure main valve was set to give a $\frac{1}{4}$ inch lead. The steam port was full open when the piston had travelled 13 inches from the dead centre. The main valve cut off when the piston was 56 inches from the dead centre, the whole stroke being $69\frac{1}{4}$ inches. The exhaust opened when the piston was $3\frac{1}{2}$ inches from the end of the stroke. The expansion valve at the trials was set to cut off when the piston had travelled 30 inches from the dead centre. As to the cooling of the live steam, there was a very great difference

among engineers, but the Leicester engines had come out remarkably well. There were rings in the piston valves. Across the port holes there were a number of bars, to prevent the rings from opening, and the steam exhausted into an angular space at the back. The engines were not coupled together, but no difficulty had been found in that respect. There were no combustion chambers in the boilers, and the products of combustion were discharged into one main flue. The rising mains were of cast iron. It simply happened that the 24 hours' tests were started at midnight, but he did not think that that made any difference. In the determination of the friction by the pressure gauges the best possible gauges were employed, and readings were taken every half hour, on an average, during the whole time. Pressure gauges were also, as a check, put down at the pump valve level.

He had been asked why he did not take the exact duty of the engines. The explanation was that the engines were tried two or three times over, and he took the lower results instead of the maximum, in order to be on the safe side. The contractor was satisfied with that arrangement. It was true that the delivery of sewage was not quite in the same proportion when the two engines were running as when only one was working. He got a rather better result under the former circumstances. To put the air vessel on the pump chamber was perhaps the right thing. Of course one would then be wanted on each pump; but still the one air vessel to each pair of engines and pumps which they now used worked very satisfactorily. It was a very large one. Neither Green's Economiser nor any other had been adopted. The temperature of the flues had not been taken close to the boilers, but near the stack. Very likely that would to some extent account for what had been pointed out. The access to the valves was very easy. There were large manholes in the valve chambers at each end of the engines, immediately in front of the suction valves. The others could be got at from the top of the valve chambers; they could be reached very quickly. A preference had been expressed for a plunger pump for sewage. He had many times heard it said that there was less wear and tear with such a pump. If he had begun with designing the engines, he might perhaps have adopted them, but no difficulty had been experienced at present. He had heard that the late Mr. Gordon was very anxious to obtain smooth working, and to distribute his strains evenly all over the engine, and it was evident that he had attained those objects. The strains were remarkably evenly distributed throughout.

Mr. Santo Crimp had asked what proportion of sewage went

to the farm. About 60 or 70 gallons a head was pumped up to the farm during rains. Whatever there was beyond that quantity was allowed to go to the outfall works. The quantity pumped up would be ten or eleven million gallons a day as a maximum. The maximum quantity of water which would be delivered by the storm culvert would be 70,000,000 gallons a day. That would show why the storm culvert was necessary. Mr. Gordon, by some very exhaustive tests, found that only about 50 per cent. of the storm water could be intercepted by a thorough separate system. The working expenses of pumping sewage to the farm, including repairs, oil, waste, water, gas and incidentals, was about 2*l.* per million gallons.

He had not gone very much into the point mentioned by Mr. Meade, namely, the results at the sewage farm, but he would say most emphatically that they were treating the sewage satisfactorily. No doubt they would ultimately have either to increase the area of the farm or adopt some method of precipitation. No very great quantity of sewage could be put upon clay land. Sludge was a very great difficulty, and it fouled the crops. One thousand four hundred acres of such heavy land could not be made sufficient for any great length of time to come without chemical treatment or precipitation. He was very much obliged to Mr. Shone for the statement that the volume of sewage would flow at the rate of 3 feet a second through the rising mains. That was certainly very near the mark.

He did not agree with Mr. Shone's statement that air would remain stationary in the sewers for weeks or months at a time. There were the currents and a variety of natural conditions which would tend to keep up a movement of the air. One of the greatest questions for sanitary engineers at the present time was to find out an efficient means of sewer ventilation, and advances were being made in that direction. Mr. Peirce had asked whether the pump was a bucket and plunger. The sewage did not go through the bucket, but through the pump valves in a separate chamber.

NEW PUMPING ENGINES.

INDICATOR DIAGRAMS.

No. 4. ENGINE.

BOILER PRESSURE 79½ lbs.
VACUUM GAUGE 27¾ ins.
I.H.P. H.P. CYL. = 95·72
" L.P. " = 109·18
TOTAL I.H.P. = 204·90

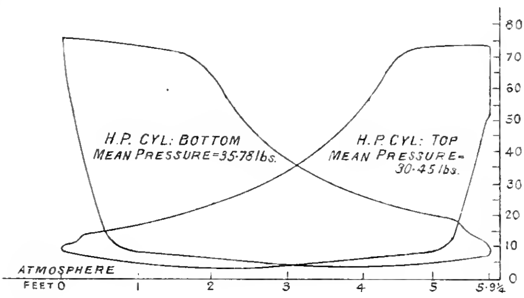


Fig. 4

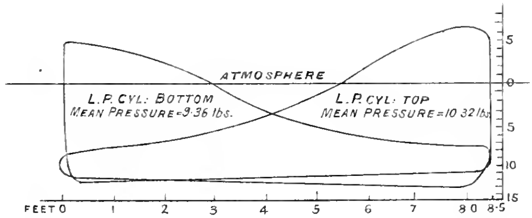


Fig. 5.

E & F N Spon, London & New York.

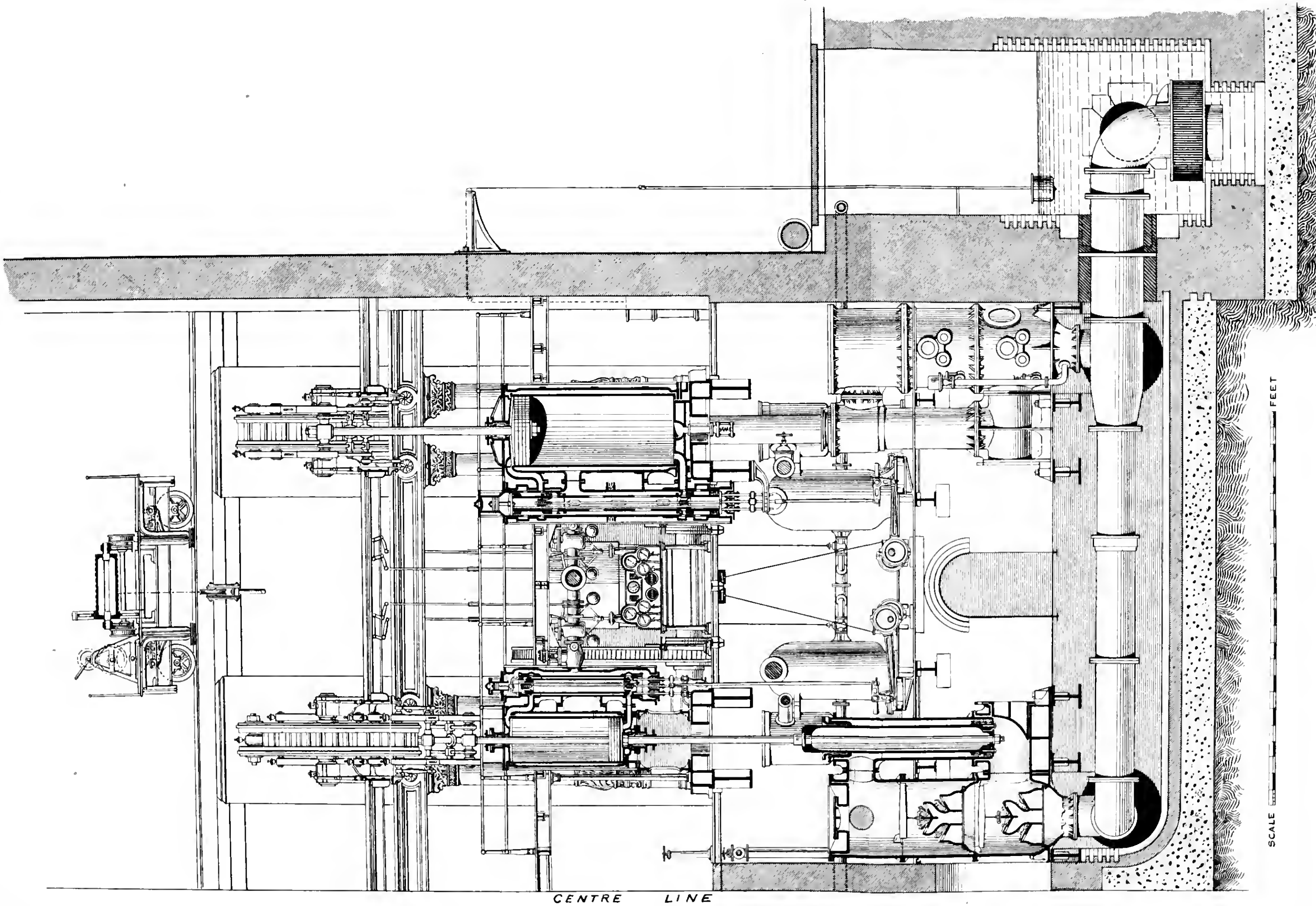


FIG. 3.

DETAILED RESULTS OF ENGINE TRIALS.

Trial No.		1	2	3	Average of these Trials.
Date of Trial		8th Sept., 1891.	9th Sept., 1891.	12th Sept., 1891.	...
Time		9-59¾ a.m. to 10-14¾ p.m.	10 a.m. to 10-6 p.m.	12 p.m. 11th to 12 p.m. 12th.	
Duration of Trial		12¼ hours	12$\frac{1}{10}$ hours	24 hours	
Nos. of Engines working		1 and 2	1 and 2	3 and 4	
Nos. of Boilers under Steam		2, 3 and 4	2, 3 and 4	5, 6 and 7	
Average Pressures—					
Barometer	ins.	30·8	30·12	30·08	30·33
Boiler steam gauge	lbs.	80·5	79·6	79·3	79·8
Initial steam gauge at cylinders	lbs.	78	78·4	78·1	78·17
Vacuum gauge	ins.	27·75	27·75	27·6	27·7
Average Temperatures—					
External air	F.	69·5°	72	66°	69·17°
Boiler room	F.	95°	99	104	99·33°
Flue at chimney, escaping gasses	F.	315	335	314	321·33°
Hot well	F.	98·5°	98	98°	98·17°
Feed water	F.	98°	97·5	97·5°	97·66
Injection water	F.	64	65°	68°	65·66°
No. of times firing		29	22	39	
Fuel Consumption—					
Total during Trial	lbs	8,624 (77 cwt.)	8,399 (74·99 cwt.)	15,667 (139·88 cwt.)	
Per actual H.P. in water lifted per engine per hour	lbs.	1·968	1·952	1·825	1·915
Per I.H.P. per engine per hour	lbs	1·741	1·712	1·65	1·712
Per sq. ft. of fire grate per hour	lbs	7·11	7	6·59	6·9
Per sq. ft. of heating surface per hour	lbs.	0·395	0·39	0·366	0.384
Ashes—					
Total during Trial	lbs.	72	51·5	184	
Percentage of total fuel		0·83	0·61	1·17	0·87
Areas—					
Grate area per boiler	sq. ft.	33	33	33	33
Heating surface per boiler	sq. ft.	594	594	594	594
Least cross section of flues	sq. ft	8	8	8	8
Ratio of grate area to heating surface		18 to 1	18 to 1	18 to 1	18 to 1
Total feed water	lbs.	83,500	88,000	155,000	
Feed water per hour per engine	lbs.	3,408	3,636	3,240	3,428
Feed Water (Evaporation).					
Per lb. of Coal—					
From actual temperature of feed water, and at actual steam pressure	lbs.	9·68	10·18	9·92	10·03
Equivalent from and at 212 F.	lbs.	11·13	12·06	11·41	11·57
Per lb. of Combustible—					
From actual temperature of feed water, and at actual steam pressure	lbs.	9·76	10·54	10·04	10·11
Equivalent from and at 212 F.	lbs.	11·22	12·14	11·55	11·63
Per sq. ft. of Heating Surface per hour—					
From actual temperature of feed water, and at actual steam pressure	lbs.	3·82	4·11	3·635	3·855
Equivalent from and at 212 F.	lbs.	4·39	4·7[illegible]	4·18	4·4[illegible]
Per I.H.P. per hour—					
From actual temperature of feed water, and at actual steam pressure	lbs	16·89	18·25	16·37	17·17
Equivalent from and at 212 F.	lbs.	19·42	21	18·81	19·753
Water drained from L.P. jacket per hour per engine	lbs	No. 1, 91·47 No. 2, 165·66 av. 128·56	No. 1, 53·44 No. 2, 161·29 av. 107·36	No. 3, 169·07 No. 4, 153·23 av. 161·15	132·36
Temperature of ditto	F. (a.v.)	208·25	208·5	211·5°	209·[illegible]
Air pump discharge per engine per hour including feed water used	galls.	9,509	10,011	9,[illegible]	9,806
Temperature of ditto	F. (a.v.)	[illegible]	98	98	98·17
Speed in revolutions per minute	(Av.) No.	12·[illegible]	12·0[illegible]	12·097	12·051
Quantity of sewage per engine per revolution as ascertained by pumping into tanks	galls.	2[illegible]7·[illegible]	2[illegible]7·94[illegible]	289·[illegible]	288·[illegible]
Quantity of sewage actually lifted per hour per engine	galls.	208,5[illegible]	20[illegible]	20[illegible],273	208,480
Quantity of sewage which would be lifted per hour per engine, calculated at the speed of 12 revolutions per minute for comparison with the requirements of the specification	galls.	[illegible]	[illegible]7,[illegible]20	20[illegible],122	207,597
Total quantity of sewage lifted by both engines during the Trial	galls.	[illegible]	5,0[illegible]	[illegible]7,124	
Head of sewage [illegible] engines including fri[illegible] taken from pressure gauges plus the depth from the gauges to the sewage in the pump wells	feet	[illegible]	[illegible]	170	1[illegible]5
Indicated H.P. (average during trial)		201·77	19[illegible]·27	197·86	199·6[illegible]
*Actual H.P. in water lifted (average during trial)		178·82	177·78	178·82	178·47
Ditto in percentage of I.H.P. (average during trial)		88·63	89·21	90·38	89·41
Duty in weight of water actually pumped per 112lbs. of coal	ft. lbs.	112,183,000	113,766,000	121,192,000	115,913,333

Note.—As these Engines can be worked safely up to about fifteen revolutions per minute, they are capable of developing well over 220 actual H.P. in water lifted.

HALF PLAN OF ENGINE HOUSE, BOILER HOUSE AND COAL STORES.

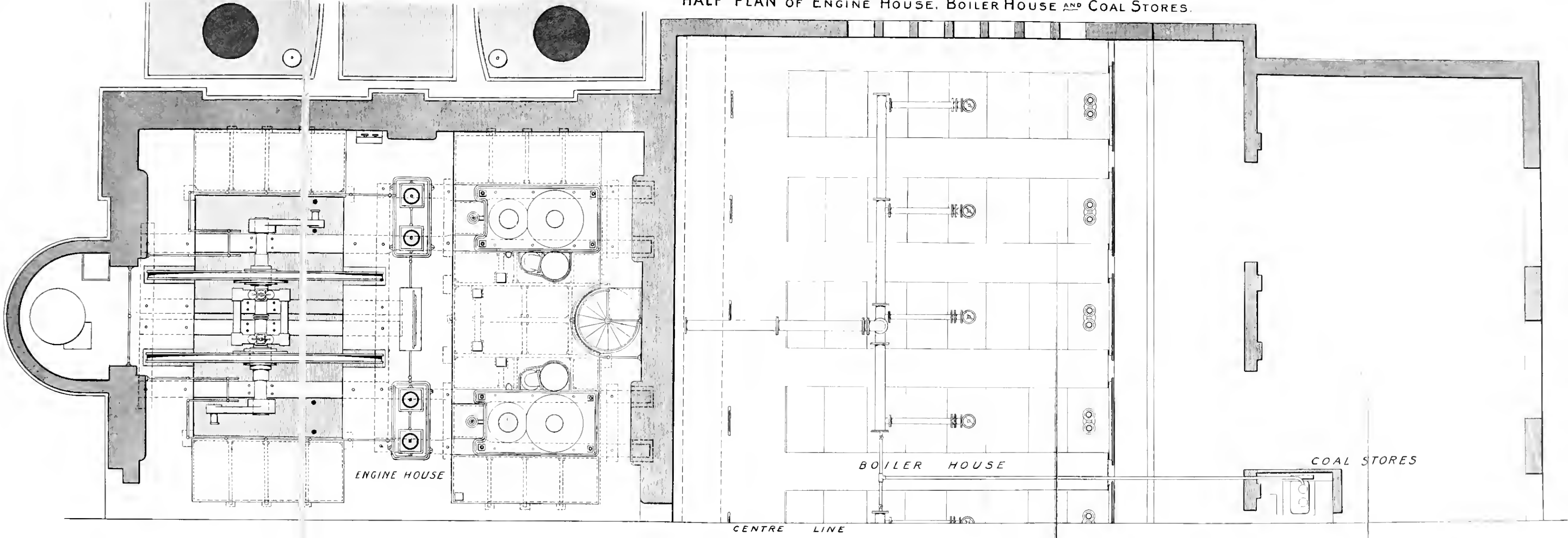


FIG. 1.

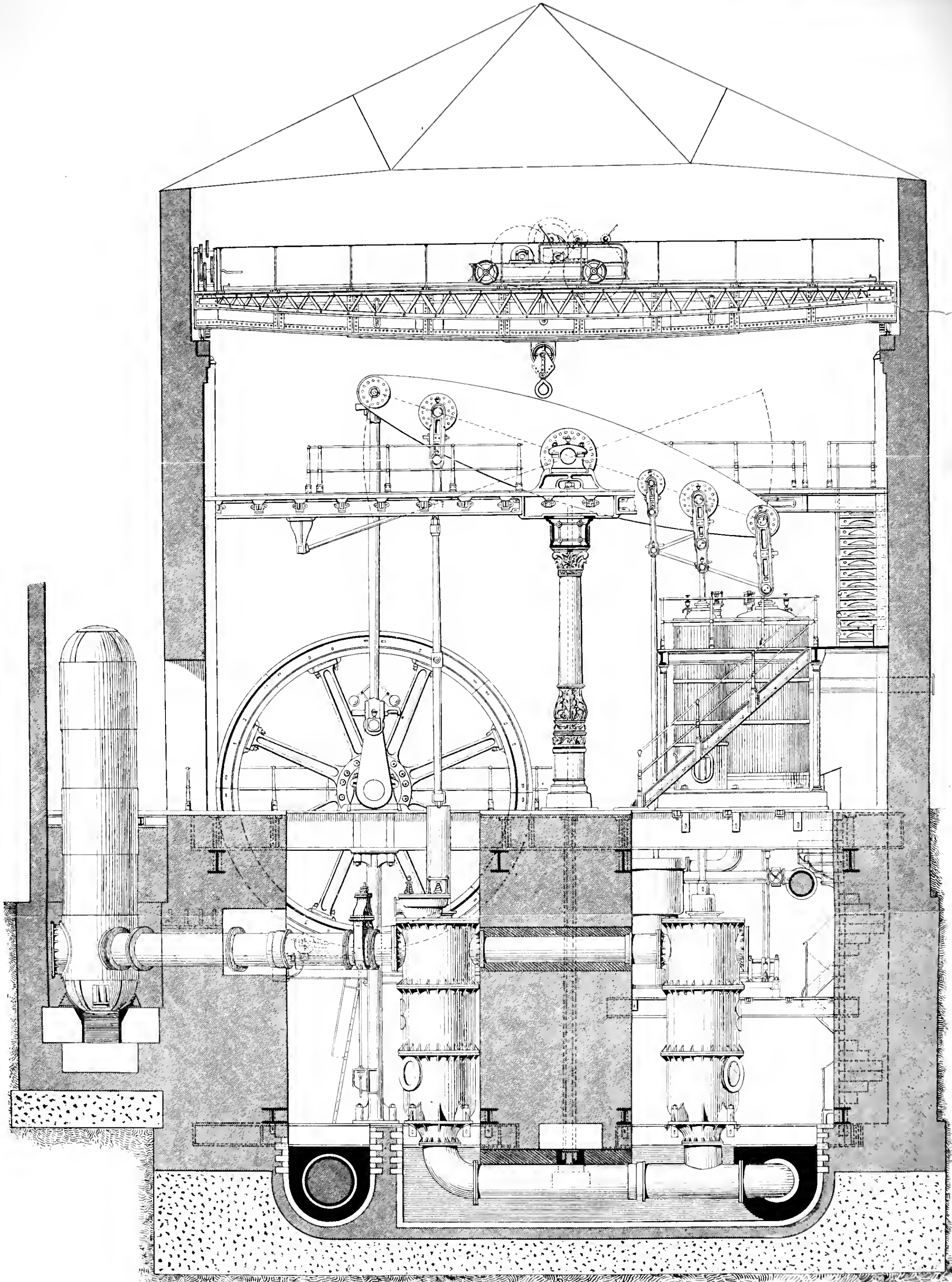


FIG. 2.

April 10th, 1893.

JOSEPH W. WILSON, JUN., PAST PRESIDENT, IN THE CHAIR.

THE CLEANING OF TRAMWAY AND OTHER RAILS.

BY HENRY CONRADI.

IN order to reduce tractional resistance, and to ensure the more economical and profitable working of tramways, a clean rail groove is indispensable. In the present paper, therefore, the author proposes to describe various appliances which have been invented with this object. Before so doing, a few observations on street-cleaning appliances in general, and their influence on the state of the rails, which form part of the streets, will be desirable.

The local authorities, to whom the superintendence of the roads is entrusted, generally employ the best methods and appliances for cleaning the streets and keeping them as clean as the general traffic will permit. As regards rail cleaning, however, some of the local authorities appear to spare no effort in the direction of preventing the tramway companies cleaning their rails and keeping the lines in the same clean state as the streets. In fact, they compel them by unnecessary and injurious restrictions to leave the lines in the muddy and dirty condition engendered by the general street traffic. It is a well-recognised fact that tram lines—which constitute one of the best means of comfortable and cheap transport, and are, therefore, a boon to the public—should have clean rails, so as to render the street transport of passengers and goods as easy and smooth as possible. Clean rails also prevent the great cruelty inflicted on horses in dragging through muddy and dirty grooves, and over a sticky rail surface, the heavily laden cars, weighing when empty from $1\frac{1}{2}$ to $2\frac{1}{2}$ tons, and when loaded, about double that weight.

It is the duty of the tramway engineer to remedy these deplorable and cruel conditions as regards animal traction, which

conditions also injuriously affect the application of mechanical power. It will be seen how contradictory and confusing are the restrictions which some local authorities impose upon tramway companies, when it is stated that the combination of a sweeping machine and a mud collector, in street cleaning appliances, which was considered by certain local authorities impracticable, and which was therefore gradually abandoned by them, was, on the contrary, held by the same authorities to be necessary for rail-cleaning appliances. They therefore enforced the use of this combination, and at the present time no rail-cleaner is allowed to be used in their district unless a mud-collector or some such appliance is attached.

The first important street-cleaning machine was constructed at Sir Joseph Whitworth's works, and was described in a paper read before the Institution of Civil Engineers and published in its Proceedings in 1847. It was a combined sweeping machine and mud collector. (See Fig. 1.) Later, about 1870–72, Mr. E. B. Ellice-Clark, Borough Engineer of Derby, in his excellent paper on "The Construction and Maintenance of Public Highways," published in the Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors (1875–76), recommended Mr. Fairbairn's street-sweeping apparatus, which also consisted of a combined sweeping machine and mud or dust collector, so arranged as to sweep the slop into the cart and carry it away.

Some years later, viz. about the year 1880, Messrs. Smith and Son, of Barnard Castle, constructed an improved street sweeping machine without a collector, and introduced their machine to local boards in the following terms:—"We think it well here to remark that we do not approve of a combined sweeper and elevator, though we ourselves made such a machine some years ago. Many local authorities, after giving this class of machine, constructed by different makers, a fair trial, have eventually given the same up as useless."

Mr. H. P. Boulnois, in his excellent treatise on "The Scavenging and Cleansing of Cities and Towns," 1881, states, with reference to street-sweeping machines:—"The value of a rotary brush sweeping machine is undoubted; the only time at which such a machine fails to do effective work, is on the occasions when the mud to be removed, owing to a peculiar condition of the atmosphere, has attained a semi-solidity, and is of a stiff and sticky consistency, when it either adheres to and clogs the brushes of the machine, or is flattened by them on to the road instead of being removed. It is, of course, necessary to sweep the ridge of dust or mud, which is left by the machine at the side of the street, into heaps by hand labour,

and to remove it by carts. Other machines have been invented for cleaning streets, which, by means of elevators or other gear, profess to raise the mud or dust direct into the carts, which are to be attached to the back of the machine; but, hitherto, these machines have been found to be too cumbersome, costly and complicated for the purpose, and they have consequently not found much favour with sanitary authorities."

It appears, therefore, from the previous remarks that a mud-collector, in combination with a street-cleaning machine, is condemned by all these authorities; but, in spite of this, some local authorities still impose on the tramway companies the condition that, if they wish to clean their rails—which it is absolutely necessary should be done—the rail-cleaning apparatus should be combined with a mud-collector or elevator, otherwise no cleaning of the rails will be permitted. The author believes he has shown that the apparatus which the local authorities condemn for street-cleaning, they compel the tramway companies to use for rail cleaning. The reason and cause for this remains to be discovered. The conclusion, however, to be drawn from the above authoritative statements is, that the rail-cleaner should be a practical instrument for removing the mud only, but not at the same time for collecting it. This does not, however, prevent the construction of a rail-cleaner combined with a mud-collector for special service, if desired.

Several machines for the purpose of sweeping tramway lines have been patented, the construction of some of which the author will briefly describe. Mr. Thomas Green, of Smithfield Ironworks, Leeds, patented an apparatus (No. 3474–1876), constructed on the principle of the rotary street-sweeping machines then in use. The two wheels in front of the driver's seat were provided with spikes to break up any hard matter which might accumulate in the grooves; and the two hind wheels were provided with flanges to run in the grooves, while the rotary brushes were situated between these two pairs of wheels, and were of the width of the rails.

During an interval of about eight years, no marked progress was made, until in 1884 Messrs. J. and E. Townsend patented an apparatus (No. 16,874—1884) for automatically clearing tram rails of snow, dirt, dust and other substances. This arrangement consisted in placing in front of a tram engine, car or other vehicle employed on tramways, metallic fixtures immediately over the tram rails or otherwise, and in front of the leading wheels. To the outer ends of these fixtures are secured slotted tool boxes, in which are mounted metallic scrapers, slightly bent on the bottom end to dip into the slot

or groove in the tram rail, and which, by the forward motion imparted by the engine or vehicle, push or force out the substances met with, and deposit them on each side of the rails. The metallic fixtures mentioned above, consist principally of swivelling tool boxes, adjustable yielding pokers or scrapers, ploughs or brushes, as also, in another modification, of revolving brushes and ice knives in combination with the scrapers.

In the following year, Messrs. Rayner and Edwards patented (3807—1885) an appliance for clearing the mud from the grooves of tram rails. This apparatus is composed of a bar fixed on the car axle, so shaped that its extremity drags in the groove, and can be raised or lowered. It is placed in the centre of the car between the wheels. A second similar contrivance is placed in front of the wheels and provided with a guide roller.

Mr. Dickinson, tramway manager of Darlaston, patented a rail cleaner in 1886 (No. 16,251), for use on tram engines. It consisted of a shaft placed in front and across the engine, and secured by brackets. At each end of the shaft was placed a scraper holder. each acting independently of the other. The shaft was provided with grooved pulleys, round which a chain was coiled, and by means of which the shaft was caused to make part of a revolution, and thus lifted the scrapers from the rails. This lifting and lowering arrangement was worked from the engine floor. The author saw the apparatus at work on several engines at Birmingham, and found it to be a very powerful and heavy contrivance.

Messrs. Record and Jordan brought out a rail cleaner somewhat similar to that of Messrs. Rayner and Edwards in 1885 (No. 3807), and in 1885 Messrs. Edwards and Record took out another patent (No. 12.641). In the first patent the tram rail groove cleaner was carried by the body frame of the car. In the second patent, the rail cleaner was attached to a separate frame carried by the axles, while in the later patent of Messrs. Record and Jordan (No. 79—1887) the cleaner is fixed to the axle box by an extension piece secured to it. The fore-end of the extension piece carries the cleaner suspended from it, and is regulated as to the depth to which it enters the groove by an adjustable link or chain.

Another contrivance which merits attention is Mr. Prosser's apparatus for clearing and watering tram and other rails, patented in 1887 (No. 415). This was not merely a cleaner to be fixed to each car, as all the previous contrivances were, but was a separate machine in itself, to be used in special service for cleaning the permanent way. It consisted of a special car

or trolley provided with all the necessary tools and appliances for the following purposes :—(1) To loosen dirt from the grooves of tram rails by means of scraping appliances. (2) To brush or sweep the loosened dirt from the grooves and top of the rail, and to carry it up an incline into a receptacle. (3) To water or moisten the tram rail, and, if necessary, the track also. (4) To distribute gravel on the track to afford a good foothold for horses, or in the case of frosty weather to distribute salt to thaw the snow or ice, to facilitate the horse traffic. The apparatus consists of a trolley running on flanged wheels. In front of the wheels are the scrapers, attached to flexible plates so that they may yield when striking against say a stone firmly fixed in the groove of the rail. They can be raised or lowered by means of levers, which are held by pawls. Series of brushes are arranged in an endless form round four chain wheels, two of which are near the rails and capable of being depressed. The other rollers are within a casing, the ends of which form part of a receptacle into which the dirt when lifted by the brushes falls, after travelling up inclined plates, from which receptacle the dirt can be discharged by sliding doors. At each end of the vehicle are water tanks with pipes for furnishing water or brine in frosty weather, for moistening the dirt to facilitate the easier action of the brushes. The brushes are actuated by chain or strap gear from pinions in gear with spur wheels fitting loosely on the axles.

The next apparatus was brought out in 1890 by Messrs. Nobes & Jackson (No. 3906). The object of this, as stated in their specification, is to fit railway and tramway rolling stock with improved apparatus for clearing stones, mud, snow and other obstructions from the rails. It consists principally of an arm pivoted to a frame, the lower end of the arm being shaped to suit the particular form of the rail to which it is intended to be applied. For tramways, the end is formed with a projection to enter the groove, and a horizontal surface to scrape the top part of the rail. For railways the end is slightly curved to fit the surface of the rail. The pivoted arms are so mounted that they hang down in a vertical position in contact with the rails when in use, clearing the track as the vehicle travels. The arms retain their normal position by means of the cam which forms the top part of the arm and oscillates in a frame. This frame is attached to the eye forming the lower end of a rod, which extends in a vertical direction, and traverses with its top part two cylinders, one of which is fixed and bolted to the bottom of the car, while the other is sliding and is fitted into the fixed cylinder telescopically. To this sliding cylinder is attached a second frame, serving as a bracket to the first frame The top

part of the rod forms an eye, to which a chain is attached. This chain is connected to a horizontal arm, supported by a stand fixed to the bottom of the car. To the other end of this arm is fixed another chain, which is fastened to a hook fixed to the floor of the car whenever the cleaner is to be raised off the rail. Vertical spiral springs are fixed in the cylinders, one of which presses the sliding cylinder downwards; the other presses the scraper upwards, tending to restore it to, and to retain it in a vertical position.

All these appliances, it will be seen, are, without exception, of rigid construction, incapable of adapting themselves with ease to the deviations of the permanent way, such as curves on the main line, passing places or crossings, or of passing over projecting tongues or points, bad joints, &c.; or of adjusting themselves to the up and down and side motions of the engine or car. To overcome these objections, the author has designed his apparatus entirely on the principle of giving elasticity to all parts, thus enabling the tool to accommodate itself to all the varying conditions and deviations of the permanent way, and to the longitudinal and lateral motions of the rolling stock to which it is fixed.

The rail-cleaner designed by the author, and which he now purposes describing, is an apparatus controlled by the driver, to be used on one or both ends of the engine or car (see Fig. 2), so that each engine or car may clear its own way on the track while running. It is brought into use according to the state of the permanent way and the requirements of the service. The Society's 'Transactions' for 1874 contain a very able paper by Mr. C. Cramp, on "Tramway Rolling Stock," describing some of the earliest designs. He states, "A great necessity exists for adopting means for obtaining a continually clear track." Down to the present day the urgency and absolute necessity of clean rails has been universally proclaimed.

Mr. W. J. Carruthers Wain, President of the Tramways Institute, expressed himself on the subject at one of its meetings in December 1891, as follows:— "I would prefer, if I were a horse, to drag an omnibus over a tramway rail, rather than drag a tramcar through a groove choked up with road dirt. I think the ideal tramway rail should always have a perfectly clean groove. It is quite the exception and not the rule to find tramway rails properly cleaned, as they ought to be for the benefit of the horses which draw cars. The strain on the horses, as everyone knows, is enormous, and very considerably depreciates them; and if you could only have a clean rail,

you would have an ideal tramway." What is true as to the horse is also correct as regards mechanical traction and rolling stock.

It is amply proved that a rail cleaner is a most essential implement, and that it is absolutely necessary for the proper performance of an economical and profitable service of tramways, street or narrow-gauge railways. No engineer or manager, who has the interest of his company at heart, should shrink from using the best method of obtaining clean rails, and not run animal or mechanical power and rolling stock to destruction by working on muddy and dirty rails. The conditions to be fulfilled by such an apparatus, to satisfy all requirements, are manifold and difficult, and the problem to be solved requires a careful study of all its numerous details, not merely as regards the apparatus itself, but also with reference to the conditions of the permanent way, and the various kinds of substances to be removed from the rails at the different seasons of the year. To resist wear and tear the apparatus must be strong, while it should be as light as possible, so as not to increase the weight hauled. According to the author's experience and researches at home and abroad, extending over a lengthy period, all the apparatus formerly constructed being in the main rigid appliances, could not follow all the irregularities of the permanent way and movements of the car.

The first attempt made by the author to combine lightness with strength is shown in Fig. 3. This apparatus consists mainly of tubes. The two main tubes, each of which contains a vertical spiral spring, are fixed, with their respective brackets, to the body of the car. In each of these main tubes is suspended an internal tube, leaving ample clearance all round for play. The spiral springs are seated in the top of the inner tubes, which are kept suspended by means of a pin or bolt screwed sideways into them. The main or outer tubes are provided on their inner side with slots for the free up and down motion of the suspended inner tubes and their pins. To each of these inner tubes is fixed a leaf spring, to which is attached the scraper-point and straight plate forming the cleaner. Two branches of the main brackets at the back of the main tubes carry a cross tube, which forms the shaft for the lifting or lowering gear. From this shaft project two strong square pins, bearing the two pins of the inner tubes. In the centre of this cross tube or shaft is fixed, horizontally, a hook, to which is linked a vertical connecting rod or lever, which is reached from the driver's seat. By moving this lever up or down, the scraper is respectively raised from or lowered to the rail. To prevent

anything getting into the horses' feet, in case of an accident to the car, two safety straps were affixed to the cross shaft, going round the tie rod of the scrapers.

While fixing this apparatus to a new tramway engine, the boiler exploded, causing considerable delay in the trial. The author, however, made a private trial of the cleaner, attached to an engine, for a short distance, on one of the worst portions of the line, which had for many years been out of repair, passing over curves, crossings and points which projected about a quarter of an inch above the level of the rails. The engine, on a flexible wheel base, swerved about two and a half inches on either side. Difficulties between the owners of the engine and the tramway authorities caused the work to be abandoned.

The author then had this apparatus reset on a horse car on another line, and after a satisfactory run of several miles, had the first well-constructed apparatus made and fitted. This apparatus has now been running satisfactorily for over eighteen months, in regular daily service, and is in use at the present time. It is represented by Figs. 4, 5 and 6. The modifications introduced at the time of its manufacture, after the author's private trial run, consisted in making the scraper spring a full coil; in making the scraper steel and the shovel plates separate, and the latter of angular shape; and also in increasing the size of each to five or six inches. The scraper and shovels were bolted to the coil spring and were made adjustable by means of a vertical slot in the scraper and shovels (see Fig. 5); while the spring was fixed to the cross bar or tie rod. The triangular brushes were also added.

Soon afterwards a second apparatus, as represented in Figs. 7, 8, 9 and 10, was put on another car. The modifications introduced in this apparatus consisted mainly in the lifting gear, using a bent lever and chain, and in replacing the inner tube by a rod. The deep bracket used for the lever at the driver's seat was also later on replaced by a simple hinge plate, fixed at the bottom of the car; but the lever fulcrum was raised about 3 inches above the bottom of the car (see Fig. 7). This alteration was made in order to remove the objection of having any part projecting much below the car, which might prove an obstruction. This apparatus was then also put in regular daily service, and is still running.

The technical difficulties having been so far overcome, it then became a question of commercial consideration and economical working. With a view to constructing the apparatus at the lowest possible cost, the author conceived the idea of using one pressure cylinder only instead of two; but as regards

this point the manufacturers charged as much for constructing the apparatus with a single as with a double cylinder. Figs. 11, 12, 13, 14 and 15 represent the single cylinder apparatus as now supplied. The transverse shaft is carried by two strong brackets fixed to the body of the car, and rests loose in its bearings to allow it to slide either way about a couple of inches. The leaf or coil spring carrying the scraper-steel and the plough-shaped plates, which perform the work of shovels, is fixed to a socket, which is itself firmly screwed to the shaft, and at the same time carries the brushes. Between the bracket and this socket are inserted horizontal spiral springs. To whichever side the shaft slides according to the deviations of the permanent way, through the scraper being guided by the groove, the spiral spring which gets compressed between the bearing-faces of the collar and bracket brings the shaft back again to its normal central position over the groove.

It is interesting and important to follow the action of the cleaner. This is at one and the same time submitted to four different and constantly varying conditions, namely:—(1) The deviations of the permanent way, consisting of the curves and variations in the gauge; (2) the side sway of the engine or car; (3) the up and down motion of the engine or car; and (4) the forward motion of the engine or car while running. The complicated movement of the cleaner is as follows:—The steel points of the scraper, the shovels and the lower portion of the coil-spring are all principally guided by the groove, while the top part or coil of the spring is more directly affected by the shaft motion, which it guides; so that condition No. 1, mentioned above, influences the bottom part of the scraper spring, No. 2 the top part of the same, No. 3 the whole coil spring, and No. 4 the bottom portion principally.

The lifting and lowering of the cleaner is effected by means of lever connections from the driver's stand, as shown in Figs. 11, 12 and 13. The dotted lines indicate the position of the cleaner when lifted; the full lines show the position when on the rail and at work. By disconnecting the hand lever at the driver's stand from its hook, fixed to the railing and throwing it forward, the connecting rod pushes back the vertical arm fixed to the shaft, thereby causing the shaft to revolve and thus turning the scraper points and plates on to the rail. By drawing the hand lever back to the dotted position, and notching it in the catch fixed to the railing, the motion is reversed and the cleaner lifted out. The small horizontal tension cylinder contains a spiral spring, which presses on one side against the

cylinder face and at the other end against a movable plate, screwed on to the connecting rod, which is hooked to the vertical lever of the scraper shaft. This plate moves freely forward and backward in the cylinder. The horizontal spiral spring constantly presses the vertical lever of the shaft backwards, thus producing a rotary back motion of the scraper shaft, and, consequently, turns the scraper points into the groove, and the plates towards the surface of the rail. The pressure can be regulated by means of the back nut of the plate on the connecting rod.

The author also uses, instead of the pressure spring with plates, the same horizontal spiral spring provided with a hook at the end. The plates or shovels are, as before, angular or plough-shaped, and are made of steel, chilled cast-iron, or any material used for brake blocks. The brushes are formed of bass, and are triangular in shape. They can be screwed up and down. The author's experience is that bass brushes generally prove the most useful. Rattan, or any kind of cane, or combinations of cane and bass, or bass and steel, are less useful. Steel brushes clog with mud, and form a solid block after a few journeys; they are very expensive, are rapidly used up, and offer considerable resistance to traction. The scraper steels and shovels are provided with a slot for adjustment to the rail. In order that this may be effected during a journey, the nuts are provided with handles, so that the conductor or driver can immediately set them without the trouble caused by the lack of spanners.

Another arrangement proposed by the author is to cause the scraper spring, with the steels, plates and brushes, to move sideways instead of the lateral shaft motion, as represented in Figs. 2 and 14. For this purpose the scraper spring with its steels and angular shovel plates, and also the brushes, are fixed to a socket, which slides on a square part of the shaft. On both sides of this movable socket are placed two horizontal spiral springs, wound round the shaft, one resting against the bracket and one side of the slide, and the other against the other side of the slide and a fixed collar. To prevent a retarding action, or biting of the slide, the shaft is bent downwards (see Fig. 8) to reduce the leverage of the coil spring from rail to slide; further, the spring is by preference fixed to the bottom of the slide, and the coil somewhat reduced in diameter, to lessen in some degree its elasticity. The latter is so great, and answers so rapidly to any deviation, that on short lengths and not sharply pronounced deviations of the permanent way, the spring alone, through the forward motion of the car, often does all the work before the slide has time to complete its lateral

motion. In the case of prolonged and sharp deviation, or heavy sway of the car or engine, the slide answers well.

As the permanent way is sometimes composed partly of grooved, and partly of non-grooved or ordinary railway rails, which occurs on tramways running in harbours or along docks, the author also shapes the scraper to the ordinary rail form, as represented in Figs. 16 and 17. In the case of composite tramways of grooved and non-grooved rails, the author fixes both types of scrapers on the same bolt of the scraper spring, which passes through the slot of the steels and plates, and when the car comes to the junction of the different types of rails, the scraper for grooved rails, for instance, is shifted upwards by simply loosening the nut at the slot, while the other for bulb rails is lowered and adjusted to the rails, an operation requiring about a minute. The apparatus is chiefly arranged to be placed in front of the wheels; but it can also be fixed in the centre of the car between the wheels.

The single and double cylinder cleaner, and the arrangement of the scraper for ordinary rails having been described, it remains to examine the work this contrivance has to perform. Fine dry dust blown about by the wind, offering no great resistance to traction, should be removed by this apparatus only after the water-carts of the town have sprinkled the road and laid the dust. In other words, this apparatus should not be brought into use for dry dust, but only when it has been slightly moistened by water.

Mud, soft, sticky or greasy slush, and snow are all readily removed by this contrivance. Mud which has been hammered in by the wheel flanges and has become very hard, requires the scraper-points to run over it several times to cut it and then to remove it. In this case the scraper points act like a pick, vibrating up and down until it is cut. For still harder mud or ice, stronger springs have to be used. Obstacles wedged in, removable only by a chisel and a hammer, are not intended to be cleared by this apparatus, which is only constructed in accordance with the power available for tractive purposes. By means of the elasticity of the coil spring, as also the given transverse motion of the shaft or the scrapers, the cleaner readily follows curves or any irregularity of the permanent way, and passes easily over joints, crossings, points, &c. A practical proof of this is afforded by its application to four cars at Reading, which have now been working over eighteen months. It has also been fixed to electrical, cable, and other horse cars.

To test the influence the rail-cleaner exercises on the permanent way, rolling stock and tractive power, during its actual work, the author carried out a series of dynamometrical experi-

ments, the average result of which shows that the tractional resistance by working the cleaner during the running of the car on muddy and dirty lines is far less than by running without it, especially when each car or nearly so carries a cleaner. The author also tried the case of starting with the cleaner down. At the start there was an increase of tractional resistance of about 20 to 25 lb.; but this occurred at the start only. The tractional resistance at the start was 80 to 90 lb.; while during the regular run on the muddy and dirty lines it was, on the average, on a straight level, 60 to 70 lb.; and on the curves and passing places, 75 to 85 lb., the curves being very sharp (about 25 feet to 30 feet radius). On very steep gradients, and sharp curves of the above radius, the tractional resistance varied from 90 to 100 lb. The drivers, of their own accord, always raised the cleaner when the car stopped and lowered it only when in motion; thus no extra strain was put upon the horses or mechanical power used. The car weighed about 1½ tons empty, and carried a varying load of 12, 19 and 22 passengers during the run, so that the average total weight was a trifle above 3 tons.

Having obtained these results, the author made a further experiment to ascertain the tractional resistance of a car running on rails cleaned by the apparatus. For this purpose a car in its ordinary regular service started with the cleaner down and cleared the rails. A second car, also in its regular duty, after an interval of ten minutes, followed, with a varying load, up to twenty-eight passengers. This second car, with the cleaner down, showed at the start and on the straight level a tractional resistance of 50 to 60 lb.; while, when running, it amounted to 35 to 45 lb. on curves, and at passing places on the level 50 to 60 lb., and on curves on steep gradients 70 to 80 lb. was indicated; so that on rails previously cleaned by the car in front the tractional resistance was, on the average, 25 to 35 lb. less, even with the cleaner down on the second car. This resistance would be still further reduced if each car or nearly so, was provided with a cleaner.

Comparing the rail cleaner with other methods, the author begs to submit the following data:—

Not cleaning the rails is the cause of rapid deterioration either of horses or of any description of mechanical power used for traction, as well as of the rolling stock, a fact generally known and admitted by engineers, managers, and in some cases by the directors themselves. It is therefore difficult to understand why so little is done in this direction, and the cleaning of the rails so completely neglected. Horses or mechanical power and rolling stock are permitted to run to destruction rather

than provision be made for the proper cleaning of the permanent way. As electricity is rapidly coming into use for tractional purposes, and is specially cited as the cheapest method, the author maintains that for electrical traction, clean rails are of the utmost importance, effecting, according to Mr. A. Reckenzaum's experiments, a saving of 15 to 50 per cent. of tractive power. This saving applies, of course, also to all kinds of traction.

Cleaning by hand is costly and non-effective. A man with a pointed scoop requires for cleaning, on the average, two hours per mile of single line under normal conditions of permanent way and weather, and double that time for a double line. Taking for the purpose of comparison, a short line of 2 miles of single line: It takes one man about four hours to clean this 2 miles of single line once, or eight hours to clean it twice, say once in the forenoon and once in the afternoon to complete his journey. Reckoning the average wages for this man at 15*s.* to 21*s.* per week of six working days, or 2*s.* 6*d.* to 3*s.* 6*d.* per day, according as to whether it is in town or country, the average cost of cleaning this 2 miles of single line twice a day will be 3*s.*, or about 9*d.* to 1*s.* per mile cleaned once a day, and in the fine season. In autumn and winter, however, the price for cleaning these 2 miles will generally rise to 1*l.* 5*s.*, and up to 3*l.* 15*s.* and 4*l.* per week, respectively. Taking 3*l.* as an average, this would represent 10*s.* per day, or 5*s.* per mile cleaned twice a day, or say 2*s.* 6*d.* per mile cleaned once a day, in the severe season of the year. The author, therefore, thinks that 1*s.* per mile of single line cleaned once a day in the fine season, and 2*s.* per mile cleaned once a day in the severe season, would correctly represent the average cost of cleaning by hand.

Watering the line is only useful to lay the dust in the hottest season. With the exception of mechanical traction, it is impracticable to make tank or pipe arrangements on the cars to sprinkle water for laying the dust, on account of the heavy water-weight to be hauled. Otherwise, watering the line is always very expensive, and at all seasons other than the hot season, dangerous, necessitating heavy and constant repairs. It causes the pavements along the rails to get loose and sink, and thus throws the permanent way out of gauge, with the ruinous consequence of producing an enormous strain on the animal or mechanical power, and on the rolling-stock. The watering of the rails moistens the mud in the grooves, but does not wash it out, and therefore leaves the rail in the same muddy condition as before. The water running from the water tanks through the pipes to the rail does not gain sufficient power during its fall to clean the rail. As to the cost of watering the line, the

author arrives at the following conclusion. Assuming, again, 2 miles of single line, it requires a water cart of about 500 gallons capacity, with a horse and a driver. For longer lines, of course, two horses to a cart of a capacity of about 1000 gallons of water, with an additional attendant, are necessary. The water cart service with one horse, cart and man, exclusive of water charges, costs 9*s.* 6*d.* to 10*s.* per day, watering twice daily. The water-cart spreads 0·51 gallon per square yard. The groove requires about 20 gallons per mile of single rail. For 2 miles of single rail 40 gallons of water will be required. The top surface of 2 miles of single rail 3 inches wide, representing 294 square yards, at 0·51 gallon per square yard, requires 150 gallons, giving for the groove and rail surface a total of 190 gallons. In round numbers, 200 gallons will be required to water 2 miles of single rail once a day. Thus for 2 miles of single line, watered once a day, 400 gallons will be required, and the cost, reckoning 1*s.* per 1000 gallons, will be 4·8*d.*, say 5*d.* Therefore the cost of the water for 2 miles of single line, watered twice a day, will equal 10*d.*; cost of cart service for watering twice per day, 9*s.* 5*d.* The total cost is, therefore, 10*s.* 3*d.*, or about 2*s.* 6*d.* per mile watered once a day.

In cleaning with the author's rail cleaner, according to the manufacturer's account, the repairs to the scrapers from January 12th to December 1892, say for one year, for the same 2 miles of single line amounted to 3*l.* 11*s.* 3*d.*, or 2·33*d.* per day. The brushes required renewing every three months, at an average price of 3*s.* each, 6*s.* the pair, say on an average 1*d.* per day; total, 3·33*d.* per day. No breakage has occurred yet; but to provide for all emergencies, we may reckon for this item 1*d.* per day more, which brings the total repairs or maintenance to, say, 4½*d.* per day. Allowing a liberal amount for breakdowns of cars, or other exceptional accidents, say 1½*d.* per day, the cost would be brought up to the outside limit of 6*d.* per day, leaving a very large margin. But this price does not merely include cleaning once or twice a day, but as often as the service of each car may require. The price of a single set of cleaners is 5*l.* 5*s.*, but this would be considerably reduced if a number of sets were ordered.

According partly to practical measurements and partly to calculation, the author found that the quantity of mud of which the tramcar had to be relieved in cleaning, varied from 77 lb. to 770 lb. per mile of single rail. In the latter case the groove was filled with one continuous coherent strip of 1 mile in length. Under these conditions the author claims to have again proved, if further proof were needed, that cleaning the rails is an

absolute necessity, and that the benefit derived from it not only relieves the horses from very cruel treatment, which no engineer should sanction, but also prolongs their period of service by about eighteen months; that it not only keeps the rolling stock in better condition, but also prolongs its use for about two years; that it not only saves mechanical power, when such is used, but also contributes to a large extent to the increase of the profits of the undertaking, by reason of the profitable and economical working of the line.

The removal of the mud thrown out of the rail, mixed with that resulting from the ordinary traffic, to the side of the road, to be eventually taken away by the dust carts, is a duty belonging to the local authorities entrusted with the cleansing of the streets and other sanitary arrangements of the district.

DISCUSSION.

The CHAIRMAN, in moving a vote of thanks to the author, said he believed this was the first time a paper on the present subject had been read before the Society. At first sight the matter might appear to be one which did not give room for much discussion, but he thought that there were many points in connection with it which could be profitably considered. The author did not state what he proposed to do with those obstacles which were occasionally to be found absolutely wedged into the rails. That was a point which was worthy of consideration. He hoped also that a little light would be thrown upon the paradoxical position which the author had pointed out in connection with the local authorities, and the clearing away or non-clearing away of such material as had been removed from the rails in the process of cleaning them. The statistics which the author had given were very *à propos*, and they seemed to show that some mechanical process of cleaning was to be preferred. The firm of Nobes and Jackson, who were mentioned in the paper, had written to point out that the statement made in the paper that their machine was "of rigid construction and incapable of adaptation to the deviations of the rails" was not accurate. Possibly there was someone present who had experience on that point. There was some amount of intricacy about the subject generally, and the author had brought before them several systems which had from time to time been devised, including his own system, which had been for some time practically at work.

The vote of thanks was accorded by acclamation.

Mr. Colam said that the subject of the paper was one in which the interest of the engineer would increase the more he went into it. It involved many mechanical problems and practical points which did not present themselves on the first blush to an ordinary engineer. A great many of the appliances referred to he had seen on the scrap heap. He was sorry to think that some of them had only been introduced for the purpose of obtaining patent rights. Dickinson's patent was, of course, only applicable for very heavy plant. It was tried for a long time in the Birmingham district, where the inventor happened to be a manager of a company. The more complicated Prosser machine aimed at doing everything, but did nothing well, and he did not think it was worthy of attention. As to Nobes and Jackson's patent, he did not think the author was quite fair to the makers when he said that it had no adjustable movement. It seemed probable that the author had referred to it with a number of others which were devoid of adjustment.

He did not think the author was quite fair to local authorities when he said that they decided not to do the very thing which they insisted the tramway companies should do. What the authorities had to do was so totally different from what the tramway companies had to do, that he did not think that the comparison was a fair one. Local authorities set about sweeping up the roads, the surfaces of which were very uneven, and they tried to get an apparatus which would elevate the sweepings into carts, and this they failed to do satisfactorily. But they could see that it was possible to introduce some arrangement by which the sweepings or the collections from a uniformly level surface, such as the rails of a tramway would be if they were grooved out, could be taken into a vehicle. He had seen many machines which had been perfectly successful in that way, but they failed for altogether other reasons. As the engineer of one of the largest tramway companies in London, he might state that it cost a London company about 1700*l.* a year to take out the dirt which accumulated in the grooves of the rails by hand, and this was independent of what they had to do to meet the difficulties of the winter period. In the case he referred to it cost about 1*s.* 6*d.* per mile of track per day to clean out the rails. That showed that Mr. Conradi's statement that the cost was from 1*s.* to 2*s.* was very fair. It must be apparent that there were other points to be considered besides cost, and one was the almost insurmountable difficulty of dealing with the stuff after it was taken out of the rails; and until some contrivance could be introduced to do that he did not think the author would be successful with his machine, or

any other machine, in London. The author said they need not be afraid of the apparatus being down and at work when the car was brought to a standstill, and thereby cause resistance when starting again, but he (Mr. Colam) did not think that it would be possible for a man to get so far over as to catch the lever when he had a pair of horses to handle in one hand, and the brake to manipulate as well. His experience of workmen was that they would save themselves all the work they possibly could, and he was afraid the apparatus would not often be used if it was left to the driver to attend to every time he stopped.

The author had boldly said that he did not propose to deal with dust accumulations unless local authorities watered the roads first; but local authorities did not usually water the roads much when they could help it, especially in early spring and autumn, when there was a great deal of dust about to fill up the rail grooves. He could not agree with the statement of the author that the dry dust offered no great resistance. His experience, based upon actual readings of the mechanical power of engines, was that dry dust was a much more serious thing than was usually supposed.

He was not quite clear with regard to Mr. Conradi's statistics as to tractional resistance. He did not understand whether the figures meant a lb. per ton load, or a lb. for a given load on a car, for Mr. Conradi did not fix himself to any particular weight of car or any particular load of passengers. Speaking roughly, he might say that his experience had been that, taking a level road with an ordinary grooved rail, the difference which he had found in the tractional resistance between a clean rail and a dirty rail was about 17 or 18 lb. Therefore the point was an important one to get over, but the question was how it was to be done. He believed that it could not be done in London unless they were allowed to leave the stuff on the side of the rails, and that would not be allowed at present. In London, with a seven or eight minutes' service of cars, there was plenty of time for the ordinary vehicular traffic in the streets to put the mud back again into the rails before the next car came along. As probably every one knew, the scoop which was used for hand cleaning in London had a flange which came on the trail and the rail, and a point which went to the bottom of the groove; and when the scoop was filled the man was supposed to take the load to the side of the road and deposit it there. That was an apparatus which complied with the requirements of local authorities in London, and he did not think that Mr. Conradi's apparatus did so.

He did not think that Mr. Conradi's calculation with regard to the water was quite correct. His (Mr. Colam's) experience

was that one bucket of water under some conditions was sufficient to loosen the mud in a rail a mile long. Wherever there was a grade which would assist, the simplest way of dealing with the matter was to go to the highest point of the grade and drop a little water into the groove. Upon indicating engines he had found very great assistance resulting from the moistening of the rails. Of course, in drawing a comparison commercially between the results of hand cleaning and machine cleaning they must have the conditions the same. It was not fair to compare hand cleaning which complied with the requirements of the local authorities with machine cleaning which did not.

He was surprised at the good round figure of eighteen months which the author had given as the extra life which was to be got out of a tramway horse in consequence of the adoption of his apparatus for cleaning the rails. Perhaps the author would enlighten the meeting as to the way in which he arrived at that figure. He would also perhaps tell them how he proposed to get two years extra life out of the rolling stock. The weight of the apparatus had not been given by the author, and as that was an important point, it would be well to add it to the paper.

When it was proposed to apply mechanical contrivances to horse cars, many difficulties had to be surmounted. The veterinary surgeon and the traffic manager had to be faced, and all sorts of excuses would be made to prevent the appliance being a success. He (Mr. Colam) once had to report upon a car starter, and having found it useful, he asked the traffic manager why he did not adopt it. That officer admitted the usefulness of the apparatus, but the reason that he gave for not adopting it was that, after the horses got accustomed to the apparatus, they would not start unless they heard the noise of the apparatus going into action behind them, and consequently when the tramway company had done with the horses and wanted to sell them, they would not fetch so much in the market as they would if they had not been accustomed to such an apparatus. Probably that excuse was given for want of a better one. It was a very good sample of the reasons which were sometimes given in discouragement of mechanical contrivances.

Mr. W. Schönheyder asked Mr. Colam what proportion the 17 lb. per ton traction which he mentioned, bore to the whole. What was the average traction?

Mr. Colam said that he found it to be about 22 lb. per ton with a clean rail, and very nearly double for a very dirty rail.

Mr. Schönheyder said Mr. Colam had stated nearly all that there was to be said on the subject. He would, however, point out, that in the arrangement by Messrs. Record and

Jordan, there were two separate scrapers, for going in opposite directions, and haudles provided so that they might be lifted out, but if the drivers did not lift them out when they ought to do so, one would go in the opposite direction to what it should, and would be carried away.

Mr. CONRADI explained that the diagram to which Mr. Schönheyder was referring showed two different examples of scrapers which did not both belong to the same apparatus.

Mr. SCHÖNHEYDER said that the cars, as they were now made, had to go in both directions, and neither of the scrapers could do that. Prosser's arrangement seemed to be a conglomeration of little sewing-machine details which, being smothered with dirt and mud as they would be, would not last very long. In the arrangement which the author had made to enable his scrapers to yield sideways, the springs on the shaft were very close to the ground. The shaft, &c., would necessarily become covered with dirt, which, apparently, would cause the scrapers to refuse to slide on the shaft. If the main springs were made sufficiently yielding for their ordinary work, so that they would yield backwards and forwards, they would also yield sideways, because the wheel-base in tram-cars was, as a rule, very short, and the curves were not very sharp, and slides might be dispensed with.

The author seemed to have introduced a very great improvement on previous arrangements, but, as Mr. Colam had very ably said, the whole point was whether the apparatus would be sufficient. He (Mr. Schönheyder) agreed with Mr. Colam that it would be of no use to sweep the mud from the rails one minute, if it would be swept back again the next. The only thing which would really be efficient, would be some kind of road-sweeping machine which would scrape the dirt out of the rails and at the same time sweep it up into a cart, and he did not see any insuperable difficulty in designing such a machine. There must be a brush of some kind, but, instead of having the brush in the form of a chain, it would be better to have a large wheel, from 3 feet to 4 feet or more in diameter, with no loose parts. That seemed to him to be the only apparatus which would answer the purpose completely. Such an appliance would be much more expensive than an apparatus attached to the car, but it must be remembered that only one such apparatus would be worked, instead of twenty or thirty as in the case of an apparatus which had to be fixed on every car.

Mr. S. D'A. SELLON said that the author had not exactly met what was required, although he had gone a considerable distance beyond what had been done before. The difficulty which he, the speaker, had to deal with in the line with which

he was concerned was that of keeping the upper surface of the rail perfectly clean. In an electric tramway it was necessary to keep the surface of the rail so clean, that the contact between the rail and the wheel was absolutely perfect. He always liked to hear any one who was discussing tramways rating the local authorities as much as possible. Mr. Colam seemed to have made friends with them, but he (Mr. Sellon) always treated them as enemies, and he should continue to do so. He would be willing to try the author's apparatus until he could find some better means to get rid of the dirt, whether he was satisfying the local authorities or not. Up to now he had always deposited the dirt from the rails at the side of the rails, and then if the local authorities liked to get rid of it they could. He had not tried that plan in London, but he had tried it in towns, the corporations of which were quite as keen as any vestry in London. He knew of no clause in the General Tramway Act providing that they should take the dirt out of the rails, and put it in the channel beside the road. This might be the outcome of a private agreement. As far as he could see, the great disadvantage in all mechanical sweepers, was a point which Mr. Colam had referred to, and that was their weight. The cars themselves were heavy enough. And again, car drivers ought not to be required to attend to the work of the sweeper in addition to their other duties.

Mr. W. G. Peirce said the only way in which he had been connected with the subject before the meeting was through supplying water for the cleaning of the rails. The Tramway Company at Richmond had looked upon the charge for water as too high, and had discontinued the use of it. The water was put on the roads when it was not required for laying dust, and was a great nuisance. It was found that it loosened the pitchings and made the road rotten on both sides of the rails.

Mr. Worby Beaumont said he had seen a good many different forms of road scraping machines invented, but after they had been tried, he had heard nothing more about them. Mr. Conradi seemed to have got nearer to the solution of the problem than any one else. He seemed to have taken a leaf from the book of the agricultural engineers who made machines which performed their operations under the most adverse conditions as to indefinite movements in all possible directions and under all sorts of variable circumstances. One of the difficulties in scrapers had been to contrive a machine which would keep to the groove of the rails, no matter how much the tramcar might dance or wander, or how sharp the curves. He should like to know why Mr. Conradi had not arranged his apparatus so that it should be added either to the axle or to the bearing that

moved with the axle, and so that there should be very little movement due to the car itself. He thought that such an arrangement would enable Mr. Conradi to simplify the apparatus. The weight of the apparatus was certainly an important point. At the same time it ought to be possible to bring the weight so low that it would pay to carry it.

Mr. Colam had made a remark which bore strongly upon another point, which was that, although it was very desirable that the work should be done, still it was not a vital thing, and cars could get along without any apparatus to clean the rails out. The tramway companies could employ men who, perhaps, would have to be kept for other work, and therefore the cleaning of the rails by an apparatus was not a piece of work which was really important to the tramway manager, or a piece of work with which he could make a good show, either at the end of the year, or at the shareholders' meetings. He thought that it was perfectly obvious that an apparatus of this kind should be as near as possible independent of either the driver or the conductor. Mr. Conradi had arranged the apparatus so as to be put into or out of gear by one handle. The difficulties in connection with that arrangement had been pointed out. The drivers had often enough to do with reins and brake, and even if they had not, they would not look favourably upon anything more. The figures which had been given by Mr. Conradi and by Mr. Colam showed how very necessary, or at any rate, how very desirable, it was, to be able to perform the work; and it was equally important, or very nearly so, for mechanically hauled cars, and more important, perhaps, for electrically hauled cars than it was for horse cars. He believed that Mr. Conradi had had his apparatus running longer than the apparatus of any previous inventor, and they must hope that he would meet with the success which the effective cleaning of the rails deserved.

Mr. Perry F. Nursey said it occurred to him that the difficulty in which the manager referred to by Mr. Colam was placed, namely, that the horses would not go on until they heard the lever click, would apply equally well to the driver letting go the brake, because a noise was caused by releasing the brake every time the tram-car was started. He did not think that the difficulty arising from the cleaning apparatus in that respect would be any worse than the brake difficulty. Out of that grew another question, which was, whether it would not be possible so to connect the cleaning apparatus up with the brake lever that, on putting the brake on and taking it off, the driver should lift up the apparatus and let it down again. There appeared to be no mechanical or other difficulty, unless it was

that it would require a stronger arm to work the two than the driver might have.

Mr. Henry O'Connor said, that in all the hand scrapers the point leaned forward, and in all the mechanical arrangements which they had been shown by the author, the point was leaning backwards, and therefore they would not clean the rails so well as they would if they were leaning forwards in the same direction as those of the hand scraper. Whether the dirt should be left on the side of the rail, or removed, was a matter outside the question. He asked the author whether he had ever tried a cylindrical brush working in the opposite direction to the wheels, to remove the dirt a sufficient distance from the rails when it was taken out by the scraper, and so prevent it from being pushed back again.

Mr. P. Griffith said, it appeared to him that all the difficulties connected with accumulation of dirt arose from the use of a grooved rail of the common or garden type. He asked Mr. Colam how the cleaning was effected in the case of a rope-traction groove. In that case there was a channel underneath in the centre of the road, that channel being, as he supposed, about the width of the ordinary tramway rail. It was surely essential to keep that open channel clean, especially as there was present in it a moving rope. Would there be any difficulty in making the tramway metal only on the outside of the wheel track, and having an open groove underneath the level of the roadway, such as was required in the case of rope-traction tramways? If this were done, could not the same arrangement be adopted for cleaning as in the case of a rope channel? There would be no moving parts, and a considerable accumulation of dirt would be necessary to cause any interference with the car-wheels.

Mr. Colam said that if he understood the speaker, he was suggesting that the rail should be bottomless, or that it should be in connection with a tube underneath, similar to the tube used in the rope tramway. The best answer to the question was that there was a Board of Trade rule in existence, limiting the depth and width of the tramway rail, and, in fact, practically deciding the shape of it. While he was speaking he might mention that he saw, the other day, the finest rail cleaner he had ever seen, although it was not intended for the purpose. It was the indiarubber tyre of a hansom cab-wheel, which was running in the groove, and it cleaned the rails admirably; and it also had the effect of sending the moist mud to a considerable distance on each side.

Mr. Conradi, in replying to the discussion, and dealing first with a remark of the Chairman, said that he had stated in

his paper that the apparatus was not to be used for obstacles wedged in the rails, and for the removal of which a hammer and chisel were required. As to Messrs. Nobes and Jackson's apparatus, he admitted that a certain vertical motion was possible, but against the pressure of the vertical spiral springs there, however, could be no free lateral motion. In his apparatus he had allowed for the car swaying freely nearly 3 inches sideways. He was fully in accord with Mr. Sellon in his opinion that the local authorities were a great impediment to the development of tramways. The managers of several companies had written to him, stating that they must not clean their rails unless they removed the stuff from the sides. As to the mud removed by a car being driven back by the traffic before the next car came, it should be remembered that it was intended that each car should clean the rail for itself.

Mr. Colam said he understood the author to say that he was proposing to put the tramway companies to the expense of fixing the apparatus on every car.

Mr. Conradi said he desired to have them on every car, but some managers only put them on alternate cars. As to the tractional resistance, he had mentioned in his paper that in the case of a car loaded to about 3 tons the tractional resistance was from 30 lb. to 35 lb. per ton, as found by practical experience. With regard to dry dust, the resistance offered by it was not so difficult to overcome and so hampering to the surface as sticky mud, snow, icy rails and slush. The reason that he did not propose to use the apparatus unless the dust was laid by sprinkling with water, was that the brush would cause the dust to fly up into the axle-boxes and wear them rapidly out. The weight of the apparatus complete was about $\frac{3}{4}$ cwt. He believed that it might even be made lighter. His information with regard to the lengthened usefulness of the horses he had derived from a veterinary surgeon, who stated that about eighteen months was added to their effectiveness. Mr. Schönheyder was right in saying that the moving parts of the apparatus would get covered with mud; but he (the author) had provided for that by covering the parts exposed to the mud with sheet tin. The apparatus had been running for more than eighteen months, and including two very hard winters. It had been said that it would be very difficult for the driver to apply the apparatus. That, however, was not the case. When a driver observed that a certain portion of the line was not clean, he simply had to push the lever forward, and the scraper would go down on the rail. This only took a second, and the driver had absolutely nothing more to do. To lift the cleaner off the rail, he had only to push the lever back. In one instance one

of the drivers made unfavourable reports on the apparatus in order to get rid of it, as he considered unhooking the lever was extra work. The manager, however, investigated for himself, and being satisfied with the cleaner gave the author permission to make further experiments.

He desired to draw Mr. Sellon's attention to the fact that Mr. Reckenzaum, the well-known electrical engineer, had mentioned that a saving of over 15 per cent. was obtained on electrical tramways through running on clean rails. Mr. Peirce had referred to the discontinuance of the use of water for cleaning the rails. It had been found that a large stream of $\frac{3}{4}$ inch in diameter failed to clean the rails and only produced mud.

The answer to Mr. Beaumont's question, as to why the apparatus had not been fixed to the axle or the bearing of the axle, was that the endeavour had been to fix the mechanism without interfering in any way with the construction of the car. Companies would not allow any apparatus which was fixed to their cars to cause alterations to the cars themselves. The only interference with the cars by the author's cleaner was the fixing of a few wood blocks and bolts. It was true, as had been said, that the introduction of the apparatus was a question of pounds, shillings and pence, and the saving in animal or mechanical power and rolling stock did not show an immediate profit. It was only after a certain time that managers could see the advantage to be derived, in the saving in the repair of the cars, and the duration of the effectiveness of the horses, or the economy of mechanical power. He reckoned that, upon an expenditure of 5*s*. or 6*s*. a day for steam power, a saving of 2*s*. would be effected by the use of the cleaner.

In reference to Mr. O'Connor's remark as to the direction of the scraper, he wished to state that in his experience he had found that when the scraper was in the backward position it pushed the dirt out quite sufficiently. It did not need to be continually upon the sides of the groove or the surface of the rail. He allowed about one-sixteenth of an inch clearance all round. The horses would have harder work if the scraper was allowed to be against the rails all the time. The small amount of mud remaining after the scraper had passed was partly taken by the brush. As to the use of a cylindrical brush, he had tried it, but he was not satisfied with its working. In his experience the rotary brush was not desirable.

Fig. 1.

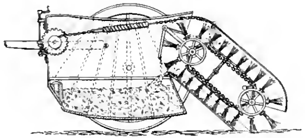


Fig. 2.

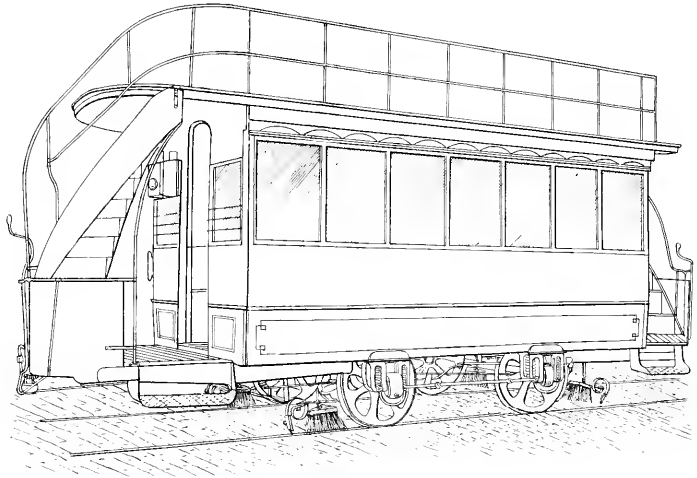
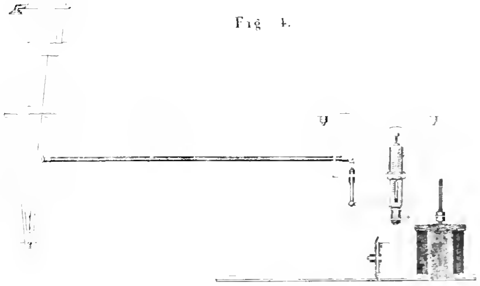


Fig. 4.



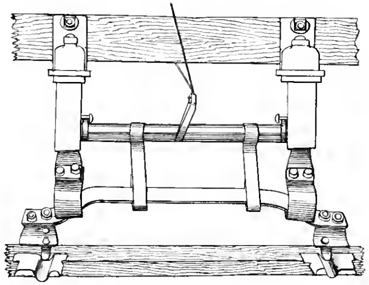


Fig. 3.

Fig. 5

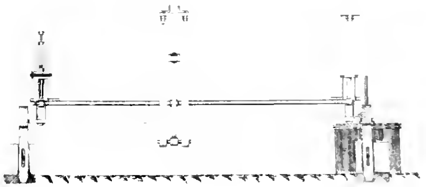


Fig. 6.

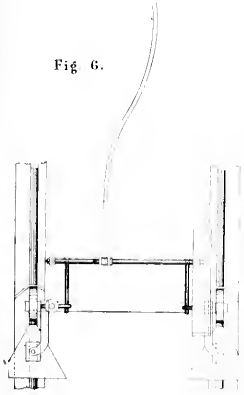


Fig. 7.

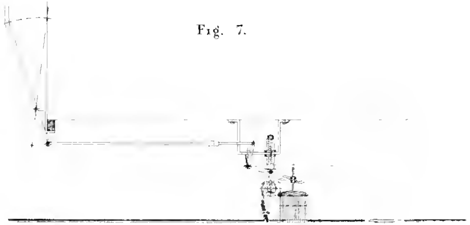


Fig. 8

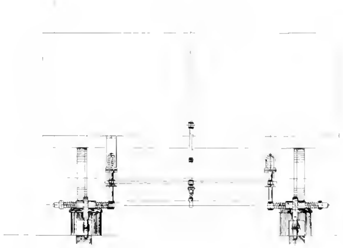


Fig. 9

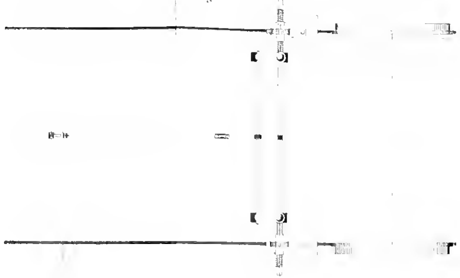


Fig. 10.

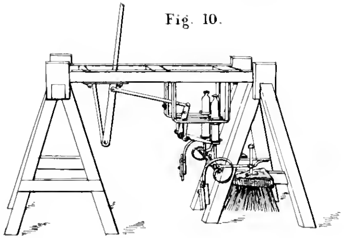


Fig. 11

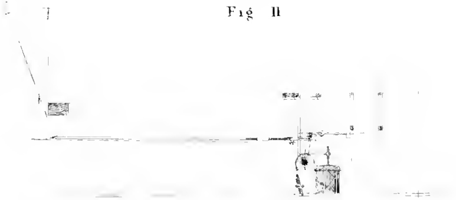


Fig. 12

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Fig. 13.

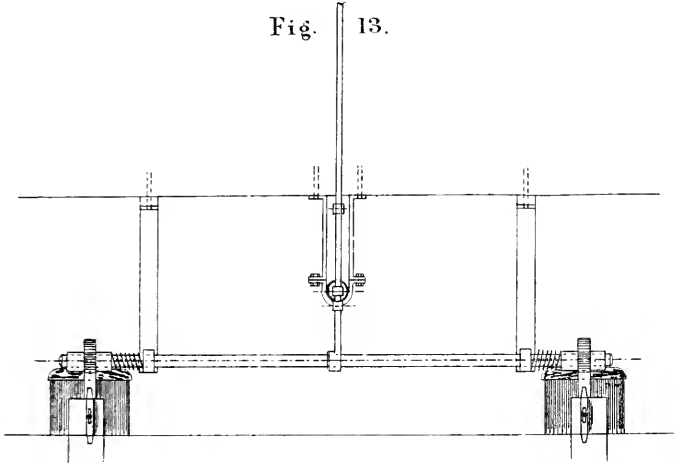


Fig. 14.

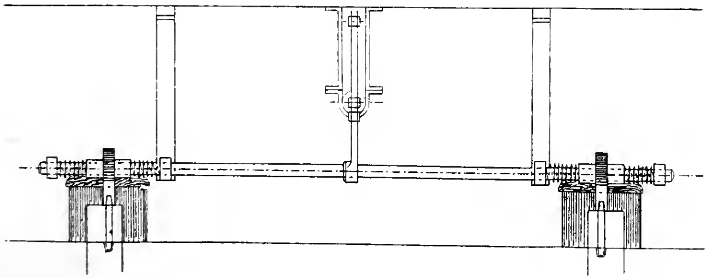


Fig. 15.

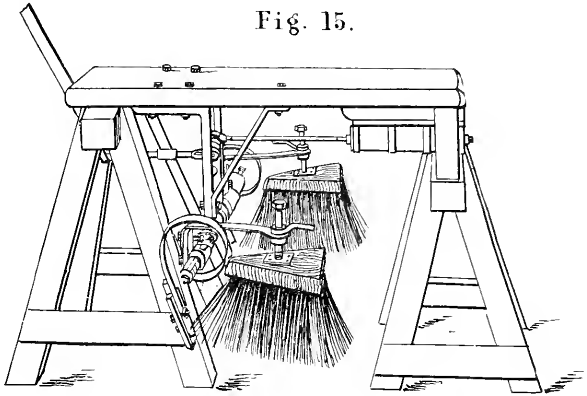
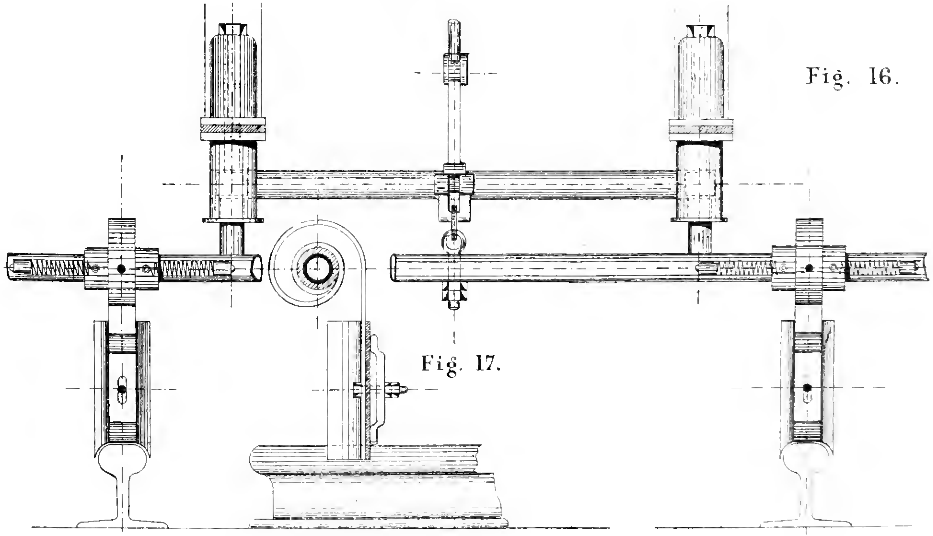


Fig. 16.

Fig. 17.



E & F.N Spon, London & New York.

May 1st, 1893.

WILLIAM A. McINTOSH VALON,
PRESIDENT, IN THE CHAIR.

BLAKE'S BRIDGE, READING.

BY EDMUND BURROWS.

BLAKE'S BRIDGE is situated upon the eastern side of the Borough of Reading, in the county of Berkshire, between Messrs. Huntley and Palmer's factory and the county goal, and forms a continuation of the East Forbury Road across the river Kennet, as seen in plan on Fig. 1. The amount of traffic passing over this bridge is considerable, as it forms a main line of thoroughfare from the eastern portion of the town to the adjacent stations of the Great Western, the London and South Western and the South Eastern Railways. In the early part of 1890, it became evident that it would be necessary either to widen and strengthen the existing structure or to erect a new bridge. Consequently, a special committee of the Town Council was appointed, and Mr. A. T. Walmisley, M. Inst. C.E., was called in to report.

The original structure, which formed the subject of investigation, was erected in 1855, and was composed of two Whipple-Murphy girders (Fig. 2) 8 feet 3 inches deep, and set 14 feet 3 inches apart, from centre to centre, over a span of 51 feet 4 inches. The ties were all inclined at an angle of about 40° with the horizontal, while the struts were vertical; the inclined or diagonal members were connected at their intersection with the top and bottom horizontal members by bolts. The top-flange and the struts were of cast iron of a special section (see Fig. 2). These struts were well designed, both as regards section and mode of fixing, and were evidently calculated simply to resist the crippling action produced by compression, as they were not bolted, but merely wedged in at their ends, thus rendering the connection practically rigid, and yet free from tension. The load from adjacent struts was communicated through the bracing bars to the top of each individual strut, while the load carried by any special strut was borne by the

lower part of the strut only, being conveyed through projecting brackets cast on to carry the transverse timber girders.

These cross girders were composed of pairs of 9 inch by 3 inch timbers resting on, and bolted to, the cast-iron brackets on the vertical struts, while the flooring was of 3 inch planks which carried 8 inches of tarred macadam, cambered longitudinally. In the main girders the diagonals and struts were counterbraced throughout the whole length of the span and formed a double system of triangulation.

The result of calculation showed that the wrought-iron ties and bottom flanges were proportionately much weaker than the cast-iron struts and top flange; and that the girders would not sustain any greater load than they were then called upon to bear. Consequently it would not have been practicable to have widened the existing bridge. Moreover, there were no footpaths to the old bridge, the entire space between parapet girders being appropriated to vehicular traffic, and it was not deemed advisable to reduce the width of carriage road. Owing to the narrow width of the bridge a continuous double line of traffic was almost impossible, with vehicles ranging in width from 8 feet 3 inches to 6 feet 2 inches—which circumstance was fortunate, both for the traffic and for the bridge in its then condition. Taking into consideration all these shortcomings, the Reading Corporation decided upon erecting a new structure, and Mr. Walmisley was instructed to prepare plans, specification and estimate. This bridge is shown in elevation at Fig. 3.

In considering the width of roadway it was found that 28 feet 6 inches would be required over all. Hence it was decided to place the main girders 31 feet apart centre to centre, which would give a clear space of 30 feet. Girders were considered most suitable, as the construction of an arch would necessarily reduce the headway at the springing, and the space for abutments would be greater than that required for piers which sustain a vertical load. The proximity of the Forbury Gardens also suggested a design of an ornamental character, to which a parallel girder under ordinary circumstances does not easily lend itself. For instance, any one who has inspected the girder railway bridge over the river Thames at Blackfriars, will notice that some talent has been displayed in designing the piers and abutments, while the girders present hard outlines, heavy in appearance. In girder work it is a difficult matter to combine architectural beauty with theoretical accuracy of design. The method adopted at Blake's Bridge was to use lattice girders 4 feet 6 inches deep, measured from back to back of the angle-irons in the flanges, and thus provide a ratio

of depth to span of about $\frac{1}{12}$, the clear span being 51 feet 4 inches.

It is found in this method of construction to be most useful and economical to have the bracing bars sloping so as to bisect at right angles, as it makes the points of junction between bracing bars and flanges 4 feet 6 inches apart, or the same as the depth. At each of these points a cross girder is fixed (see Figs. 4 and 6), suspended to the bottom of the main girders by eight $\frac{7}{8}$-inch double-nutted steel bolts, the cross girders being stiffened at their connection by the angle-iron brackets upon either side as shown at Fig. 6.

These girders are 1 foot $6\frac{1}{2}$ inches deep at centre, and as the width of bridge is 31 feet, this gives a ratio of depth to span of about $\frac{1}{20}$. This is a much smaller ratio than is advisable where circumstances will permit of a larger one, since, strength for strength and span for span, a shallow girder is necessarily heavier than a deep one, but in this case the cross girders receive the assistance of the floor plates in distributing the strain. It was desirable to keep the level of roadway down, while the Thames Conservancy wished to have a clear headway of 8 feet throughout the width of the bridge. It was, however, pointed out to the Conservators that there was but little river traffic over the Kennet immediately under the bridge, so by their permission the headway was reduced to about 6 feet 8 inches at the sides, while it was maintained at about 7 feet at the centre, there being a camber of 4 inches at the centre of main girder.

The foregoing conditions necessitated the reducing of the depth of cross girders to a minimum, and by suspending them from the bottom flange of the main girders the depth of parapet was saved and no addition of handrail was needed beyond that necessary to form a coping. The transverse girders are composed of a horizontal bottom flange, and a top flange having a camber of 4 inches, the two being braced together by a double system of triangulation, with the lattice bars placed at an angle of 51 degrees.

The loads on the bridge are efficiently distributed by the trough flooring (Fig. 7), which is 5 inches deep and is riveted to the cross girders over the entire surface of the platform. In railway bridges, where the live load is always taken by the structure at known points, it is not so necessary to distribute the load over the cross girders by means of continuous flooring; but it must be done in the case of a road bridge like the present, where the travelling load in the shape of traffic may come on in any transverse position. The troughing is laid with its ridge and furrow parallel to the main girders and is covered

in with concrete to about $1\frac{1}{2}$ inch above the ridges all over the bridge (Fig. 7). On this concrete is laid wood paving composed of Baltic yellow deal blocks 4 inches thick. The blocks were laid in rows running across the direction of traffic, with a $\frac{1}{4}$-inch space between the rows, which was filled in with boiling pitch, and the whole was grouted up with cement grout. The pitch serves to cause adhesion between the blocks and the concrete on which they lie, thus preventing the cement grout getting underneath and floating the blocks, thereby producing an uneven surface.

On the west side of the bridge the footpath is 5 feet 2 inches wide from the centre of main girder to the edge of kerb, and is composed of asphalt on concrete carried by the corrugated flooring 5 inches deep.

On the east side, the footpath is only 2 feet 6 inches wide, and is merely intended to serve as a fender to keep the traffic off the girder, and form a gutter. Both these footpaths are edged with 12 inch by 6 inch granite kerb, rising about $4\frac{1}{2}$ inches above roadway.

From the foregoing particulars the data for the calculation of dead loads supported by the bridge are obtained. The live loads provided for were those produced by a 15-ton steam-roller, with a wheel base of 10 feet 10 inches, the rest of the bridge being covered by a crowd averaging 1 cwt. per square foot. The greatest load produced by the steam roller on one cross girder was that due to the driving wheels, i. e. 9 tons on the pair of wheels. The greatest bending moment in the flanges of the cross girder was produced when this load was over the centre of the girder, while the remainder of the 30 feet sustained a distributed load of 1 cwt. per square foot. To these must be added the dead loads due to flooring, &c., supported by the girder, together with the weight of the girder itself. These loads produce a maximum horizontal stress in the flanges at the centre amounting to $51\frac{2}{3}$ tons; to sustain which there is a flange area of 11 square inches after deducting rivets for the bottom flanges. The sections of the bracing bars are worked out by finding what condition of loading will produce the maximum stress in the bars. In this case, the maximum stress was found to be 7·84 tons, and a sectional area of 2·75 inches was provided to sustain this. All the lattice bars in these small girders are made uniform in section for the sake of economy, although in reality the stresses diminish from the abutments to the centre.

The maximum flange stress in the main girders is 171·7 tons in the centre of the girder, for which a sectional area of 36·37 inches is provided in the top flange, made up of three plates

13 inches by $\frac{1}{2}$ inch, and two angle-irons 6 inches by 6 inches by $\frac{3}{4}$ inch, while in the bottom flange a sectional area of 33·47 square inches is provided after deducting for rivets.

The maximum stress in the diagonals amounts to 37·75 tons in compression, for which 11·6 square inches sectional area is provided; while the greatest tension is 44·45 tons, sustained by an area of 9 square inches.

The level of the headway of the old bridge was 126·48 feet above Ordnance datum. This level was maintained, and the new girder erected with a camber of 4 inches at the centre. The level of the top of the new platform in the centre of roadway at the centre of the bridge is 129·35 feet above Ordnance datum.

The contract for this work was divided into two portions, viz. (1) the ironwork and erection, and (2) the foundations, abutments and masonry. Messrs. Handyside & Co. obtained the first contract, amounting to 1027*l.* The cast iron used in the bed-plates and ornamental work had to be of the best quality soft grey iron, perfectly sound, and free from sand-holes and air-holes. The test bars were 42 inches long by 2 inches by 1 inch. Each bar, when cold and supported on its 1-inch face upon edges 3 feet apart, had to bear a weight of 28 cwt. at the centre, with a deflection before fracture of not less than $\frac{5}{16}$ of an inch.

It was decided to make the superstructure of the bridge in mild steel, on account of it being easier to obtain the 6-inch by 6-inch angles in steel than in iron. The steel used was specified to be capable of bearing from 27 to 30 tons per square inch, with an elongation of 20 per cent. in 8 inches. In steel, the elasticity, measured either longitudinally or transversely, is more uniform than in iron; hence it is unnecessary to specify a condition for transverse measurement.

In Blake's Bridge a method for relieving the naked appearance of a plain lattice girder has been adopted which might be more extensively employed in similar structures. Beauty of form cannot well be attained by means of straight lines, and there seems to be, in many cases, a prejudice against employing cast-iron ornamentation in wrought-iron or steel structures, and the reason is not far to seek. In fixing cast-iron ornamental pieces to such structures it has been found to be a difficult matter to so connect them that the cast-iron work shall not be subject to prejudicial strain. In Blake's Bridge the difficulty has been overcome in the following manner. The central ornament in the bays, shown at Fig. 8, is bolted to the web-plate of the bottom flange by three bolts. The middle $\frac{7}{8}$-inch bolt is put through a circular hole in the web, while the two $\frac{3}{4}$-inch

bolts—one either side of this bolt—occupy holes which are slotted horizontally. Then the ornament is attached to the web-plate of the top flange by a $\frac{3}{4}$-inch bolt, which passes through a vertically slotted hole in the web. It will thus be seen that the flanges and lattice bars of the bridge are free to expand and contract by the action of either temperature or vibration without having any injurious effect on the cast-iron centre pieces, which simply fill up the parapet.

It is not advisable to connect the lattice bars at their point of crossing in any way, though often done, as may be seen in Charing Cross and other bridges; for if they are attached to each other secondary strains are produced in the bars, which should be avoided. This difficulty has been successfully overcome in Blake's Bridge. At Fig. 9 are shown sections taken at the crossing of the struts and ties. It will be seen that each ornamental part simply acts as a distance piece, and is only attached to one bar, thus allowing the struts and ties to act free of one another.

Messrs. Parker & Co., of Cardiff, obtained contract No. 2, for the foundations and masonry, the cost of which was 2220*l.* The foundations, upon which they commenced in November 1891, proved a somewhat difficult undertaking. With the view of making use of the existing abutments, the main girders, carrying the platform, were supported upon four piers constructed of brickwork in cement. Having, for the examination of the abutments and for the construction of the above piers, driven a dam round the south abutment of the old bridge, allowing sufficient space for the additional work, a 6-inch centrifugal pump was started, but failed to free the dam of water. It rose freely from under, and from the back of the old abutment, which was built upon piles. With the view of offering as little impediment as possible to the navigation, the dam was not formed for the north abutment until that on the south side had been removed. The land on the south side of the bridge is practically an island, composed of gravel beds and sand overlying chalk at a depth of about 17 feet, as shown by trial borings taken on the site of the new abutments. Hence a great quantity of water came from the land side and floor of the dam. It was thought inadvisable to put on extra pumping plant, for fear of damaging the foundations of part of Messrs. Huntley and Palmer's factory, which was in close proximity to the east side of the work. It was therefore decided to drive a dam completely round the work, and for this purpose it was necessary to stop the vehicular traffic on the bridge, which was closed for fourteen days. The roadway was opened up to a depth of 10 feet, that is, to about water-level, and a row of 13-feet piles

driven tightly together. The excavation was then filled in, and the road re-opened for traffic. The dam having been driven almost completely round the work, pumping was resumed, and the water-level at once began to lower inside, and in a short time the foundations were laid bare.

It was found that the proposed position for the new pier and wing-wall at the south-east corner was occupied by a portion of some old wing-wall standing on a group of piles driven so tightly into the soil that it was very difficult to draw them. Consequently the new piles, on which it had been decided to build the piers, and which were of oak 13 inches square, were driven wherever a space could be found to accommodate them. Although not very symmetrical in plan, they served the required end, in that they were well under the pier. Five of these piles were driven immediately under each pier, while the wing-walls and central portions of the new abutments, which take little load, were supported upon pitch-pine piles 10 inches square and driven 3 feet 3 inches apart centre to centre. The heads of these piles having been sawn off to the same level, the piles were connected by means of 6-inch by 12-inch cross pieces let into and spiked to the sides of the piles at the top. These cross pieces also served to support the 6-inch timber capping. Round the heads of the piles and between the cross pieces concrete was deposited and allowed to set before the capping was fixed. The brick footings were then commenced, and the pier was carried up without further difficulty. Each offset in the footings was made two bricks deep, in order to obtain a good bond, and at the same time to have headers throughout the top course of each offset.

The new work was made up to the old by means of a straight joint, so that any settlement that might take place in the new brickwork would not affect the old. The oak piles under each pier were driven by a 1-ton ram, falling from a height varying from 7 to 12 feet. They were made to enter the chalk rock, and at the last few blows of the ram they had to penetrate less than an average of $\frac{4}{5}$ inch per blow. The timbers for the piles as they arrived on the ground were usually about 18 feet long, so that it was necessary in some cases to scarf a length on. This was done by cutting a recess $6\frac{1}{2}$ inches deep on the head of the pile already driven, and also on the piece about to be spliced on, and then connecting the two by means of two wrought-iron straps.

The author is of opinion that a heavy ram with a small fall is more effective than a lighter ram with a longer fall, as the latter will often shatter the pile before its limit of driving is reached. There is no theoretical formula that can be used to

accurately give the weight-bearing capacity of piles, but many empirical formulæ may be found in various works on the subject which give equally various results. The most practical of these, in the author's opinion, is one formulated in Trautwine's Pocket Book, since it has been compared with many observations in actual work, and found to be fairly reliable. It is as follows:—

$$\begin{array}{c}\text{Extreme load}\\ \text{in tons}\end{array} = \left\{\frac{\left(\begin{array}{c}\text{Cube root of}\\ \text{fall in feet}\end{array}\right) \times \left(\begin{array}{c}\text{Weight of}\\ \text{ram in lbs.}\end{array}\right) \times \cdot 023}{\text{Last sinking in inches } + 1}\right\}.$$

In the present instance the weight of the ram was 2240 lbs., the fall 9 feet, and the average penetration at the last few blows under $\frac{4}{5}$ inch, so that the above formula becomes

$$\frac{2 \cdot 08 \times 2240 \times \cdot 023}{\frac{4}{5} + 1},$$

which gives $59\frac{1}{2}$ tons as the extreme load on each pile. The factor of safety varies, according to the soil, from $\frac{1}{2}$ to $\frac{1}{12}$ of extreme load. In this case, since the piles are driven through gravel into the chalk, it will be quite fair to take $\frac{1}{4}$ of extreme load as safe. This gives about 15 tons safe load on each pile; and, there being 5 piles, 75 tons on the whole foundation of pier. The total load that it is possible to place on one pier, when the bridge is completely loaded, and with the 15-ton steam roller as near as possible to that pier, gives a reaction amounting to about 71 tons; so that each pile has to sustain a trifle over 14 tons.

The concrete was composed of 6 parts of best Thames ballast to 1 part of Portland cement of best quality. The brickwork was set in compo consisting of 3 of Portland cement to 1 of sand.

The foundations on the north side did not present such difficulties as those across the river, and it was not found necessary to dam completely round the work, but only immediately in front of the abutment.

It will be observed, on reference to the plan (Fig. 1), that the river is considerably narrower under the bridge than at any other point. This fact may account for the scouring that had taken place under the old abutments. The piles on which the brickwork stands were plainly visible, and large cavities were found between the heads of these. To remedy this, the engineer, after inspection, ordered a row of small timber sheet-piles to be driven at a distance of about 3 feet 3 inches from the abutment,

and at a height of 18 inches above the river-bed. Concrete was deposited behind the piles and well rammed into the cavities, and sloped off on the surface. This protection was extended round the foundations of the new work.

After the piers and abutments had been completed, and the girder bed-stones fixed in position, an attempt was made to raise both the new main girders before interfering with the traffic, these girders both having positions outside the old main girders. It was found almost impossible, however, to raise the east main girder before the removal of the old bridge. Each of the new main girders had been delivered in one piece 55 feet long, and weighing about 10 tons without the central ornaments. The west main girder was erected in the following manner:—Having placed it upright upon rollers on a timber platform, a winch with block-and-fall arrangement was secured in position on the opposite bank, and the tackle carried across the water and secured to the end of the girder. The winch was then started, and when the end of the girder had sufficient overhang, it was lowered on to a barge having a staging and packing pieces. The barge was then floated across the river and the girder deposited upon the cast-iron bed-plates by means of hydraulic jacks.

These bed-plates, which form a sliding contact at one end of the girders, have a firm seating of sheet lead. In the case of beams which support light loads, perhaps felt is preferable for a seating, but where the load is sufficient to crush lead it is advisable to use this material.

Provision had to be made for carrying the gas and water mains temporarily across the river. For this purpose, iron hangers were attached to the bottom web-plate of the newly erected girder, which carried the 3-inch gas main across. The 6-inch water main was taken across, resting on the top of the girder. Everything was now ready for the removal of the old bridge, which was packed up on barges from below, and removed piecemeal. The east main girder was then erected in a similar manner to its companion, and after careful adjustment of the two, the cross girders were at once proceeded with. Provision had been made for the carrying of three cast-iron 8-inch gas mains, and a 6-inch water main through the girders, across the bridge. In each cross girder there were seven holes, $10\frac{1}{8}$ inches in diameter, see Fig. 7, formed by cutting away the web-plates between the lattice-bars. After every two girders had been fixed, the pipes were threaded spigot first, as the holes would not admit of the socket being passed through. From this point the work proceeded without difficulty. The steel troughing

was next fixed, and the concrete laid, on which the wood blocks were deposited, and the bridge was opened for traffic on October 6, 1892, two days before the expiration of the two months during which it was stipulated the traffic should be closed. While the bridge was closed, the approaches were improved by the Borough Engineer, Mr. A. E. Collins. At the opening of the bridge there still remained the wing walls, pier caps and copings to complete. The caps are of brown Portland stone, and were cut from solid blocks. Their road faces are decorated as shown at Fig. 10. The time occupied, from the signing of the contracts to the completion of the work, was about 13 months.

The total quantity of steel in the girders and connections is about $42\frac{3}{4}$ tons, and in the flooring $14\frac{1}{2}$ tons. The weight of the cast iron in ornamental work and bed plates is nearly 3 tons. All the rivets are of steel, being $\frac{7}{8}$-inch in the girders, and $\frac{5}{8}$-inch in the flooring. The main girders are surmounted by a moulded American oak handrail, as shown in Fig. 11, this wood being specified as it can be obtained in greater lengths and straighter in the grain than the English variety. It is also more easily fixed and fitted than a handrail of cast iron. The total cost of the bridge, together with the improved approaches, was 4500*l.*

It was desirable to carry out the testing of the new bridge without interfering with the traffic, and for this purpose, the author, as resident engineer, placed 12 water-vans, a 10-ton steam roller, and other movable loads at the contractors' disposal. The test was carried out at daybreak; the water-vans having been filled and weighed, were drawn on to the bridge, and packed close together on either side, while the steam-roller and other weights, including horses and men, were arranged between them. The total test load was $63\frac{1}{4}$ tons, and the deflection at the centre was found to be $\frac{3}{16}$ inch, the girders taking a permanent set of $\frac{1}{16}$-inch only on the load being removed.

Calculations for Strains.

The author will now record the method of calculating some of the more important strains in the members of the lattice girders which form the structural framework of the bridge. It is necessary to begin with the transverse girders, because the data for the loads and strains communicated to the main girders are not definitely known until the cross girders are designed.

DEAD LOAD SUPPORTED BY ONE CROSS GIRDER.

	tons	cwt.	qrs.
Corrugated flooring 34′ × 4′ 6″ × 16·1 lb.	1	2	0
Concrete in troughing 31′ 6″ × 4′ 6″ × 42·8 lb. ..	2	14	1
„ to footpaths $5\frac{1}{2}$ cubic feet × 137 lb.	0	6	3
Longitudinal footpath girders	0	3	2
Granite kerb to both footpaths	0	7	3
Paving „ „	0	4	1
Wood paving in carriageway	0	13	0
Three 8 inch gas-mains (cast iron)	0	5	2
One 6 inch water-main (including water)	0	1	4
	5	19	0

Or say 6 tons distributed.

The transverse girders themselves weigh about 2 tons each; and this, with the supported load, gives 8 tons distributed as the dead load taken by each transverse girder.

To find the maximum strain produced in the flanges of these girders, it is necessary to consider them fully loaded with the steam roller, as shown on Fig. 12, and a crowd averaging 1 cwt. per square foot. The greatest strain in the flanges will be produced when the hind wheels of the steam-roller are vertically over the centre of the cross girder. The load on the pair of hind wheels will be 9 tons; and this load, concentrated at the centre of the girder, is equivalent to a load of 18 tons distributed. The remainder of the girder may at any time be covered by the supposed crowd, and supports 5 tons distributed. But a portion of these live loads—say one-half—is communicated to the adjacent cross girders by means of the flooring; hence the total live loads may amount to about 12 tons distributed.

From the foregoing remarks it will be seen that the total live and dead loads amount to 20 tons distributed over the girder. The maximum strain at the centre of either flange is found by the formula $\frac{W\,L}{8\,D}$, where W = weight distributed in tons, L = span = 31 feet, and D = depth of girder = 1′ 6″. The maximum strain therefore $= \frac{20 \times 31}{8 \times 1\frac{1}{2}} = 51\frac{2}{3}$ tons tension in bottom flange, and compression in top flange. The sections provided in the top curved flange are (2) L irons 4″ × 4″ × $\frac{1}{2}$″ and a web plate 4″ × $\frac{1}{2}$″, amounting to a total of 9·5 square inches. This gives nearly 5·5 tons per square inch as maximum strain in the metal, but then we have the assistance of the floor plates attached to the top flange. In the bottom flange there is a section amounting to 11 square inches, after deducting for rivet-holes. Hence the metal in this flange endures a maximum strain of 4·7 tons per square inch when the girder is fully loaded. The designing of the lattice bars

is more a matter of convenience than calculation in such small girders as these, and is arranged to suit the connection to the flanges. The weights of, and loads supported by, the cross girders being known, the main girders may now be proceeded with.

The dead loads, supported at each joint or "node" of the main girder, are as follows—the bottom flange only being considered as loaded.

	tons	cwt.	qrs.
Weight of 4′ 6″ of main girder, hand-rail, ornamental work and bolts	0	19	1
½ weight of one cross girder	1	0	0
½ dead load on one „	2	19	2
	4	18	3

To estimate the live load at each node of bottom flange, imagine the whole bridge to be supporting 1 cwt. per square foot. This amounts to $29' \times 4'\ 6'' \times 1$ cwt. $= 6\frac{1}{2}$ tons at each cross girder, half of which or $3\frac{1}{4}$ tons will be communicated to either main girder.

It is evident that the maximum strains produced in the flanges by the steam-roller will occur when the engine is as near as possible to one of the main girders. Hence the driving wheels are supposed to be close up against the kerb of the eastern footpath. (See Fig. 12, Diagram I.).

The reaction at point a from the driving wheels

$$= \frac{(\overset{\text{tons}}{4 \cdot 5} \times 27'\ 8'') + (\overset{\text{tons}}{4 \cdot 5} \times 22'\ 3'')}{31'} = 7 \cdot 25 \text{ tons.}$$

The reactions from the leading wheels of the engine are neglected in these calculations, although it would have been more correct, theoretically, to consider them.

This $7 \cdot 25$ tons acting at one point at a time only, will produce the same strains throughout the girder as a distributed load of $\frac{7 \cdot 25 \times 2}{12} = 1 \cdot 21$ tons at each joint.

Hence the total live and dead load at each joint can now be summed up.

	tons	cwt.	qrs.
Dead load from main and cross girders	4	18	3
Load due to crowd	3	5	0
„ steam-roller	1	4	1
	9	8	0

Or say, $9\frac{1}{2}$ tons in each bay.

Each bay is 4 feet 6 inches in length, which gives $\frac{9\frac{1}{2}}{4\frac{1}{2}} =$ 2 12 tons per foot run of girder as the total load supported. The strain in either flange at the centre will be equal to $\frac{w\,l^2}{8\,\mathrm{D}}$, i.e. the maximum "bending moment" divided by the depth.

w = load per foot run = 2·12 tons;

l = span = 54 feet;

D = depth of girder = 4 feet 6 inches (measured from back to back of L irons).

The strain is therefore $= \frac{2 \cdot 12 \times 54 \times 54}{8 \times 4 \cdot 5} = 171 \cdot 7$ tons tension in bottom flange, and compression in top; to sustain which a sectional area of 36·37 square inches is provided in the top flange, the metal undergoing a maximum strain of 4·7 tons per square inch. In the bottom flange there is a sectional area of 33·47 square inches (after deducting for rivets), hence the metal endures a maximum strain of 5·13 tons per square inch.

The bending moments at any points in the flanges vary directly as the ordinates of a parabola. Knowing this, a curve of maximum bending moments may be plotted as shown in Fig. 12. The maximum bending moment at the centre of girder is 772·74 foot-tons.

From the centre of span, set up a perpendicular (171·7 × 4·5) = 772·74 foot-tons to any suitable scale: this will give the vertex of the parabola, which is made to pass through the ends of the line representing the bottom flange.

The use of this operation is twofold. In designing the cover plates, the horizontal strain at the point where the plate occurs may be found by scaling the height of the parabola and dividing by the depth. Secondly, the lengths of the plates of which the girder is built may be ascertained. The section at the centre of bottom flange is made up of three plates $\frac{1}{2}'' \times 15''$ and two L irons $6'' \times 6'' \times \frac{3}{4}''$, representing areas of 7·5, 7·5, 7·5 and 16·87 square inches respectively. Each plate or angle may be assumed to take an amount of strain proportional to its sectional area. Divide up the vertical height of the parabola at the centre, in the proportions 7·5, 7·5, 7·5 and 16·87. Through the points thus found draw horizontal lines to cut the curve of bending moments; these points in the curve give the lengths of plate required. The L irons and first $\frac{1}{2}$ inch plate are made to extend the whole length of the girder.

Main Girder: Lattice Bars.—Suppose a weight W divides a girder into two portions m and n ($m + n = l$ = span).

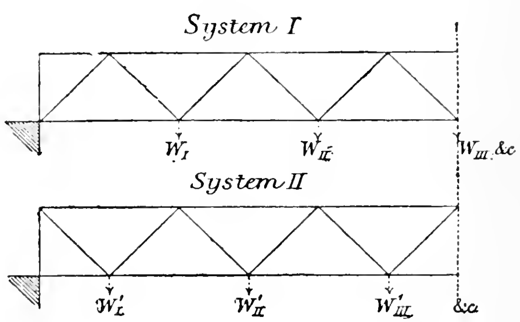
Then the vertical shearing stress in the portion m will be $\frac{n}{l}$ W;

and in the portion n, $\frac{m}{l}$ W. These stresses are assumed to be transmitted to the abutments through the bracing bars. The vertical force may be resolved into its vertical and diagonal components, so that

$$\frac{\text{Stress in diagonal}}{\text{Vertical shearing stress}} = \frac{\text{Length of diagonal}}{\text{Depth of girder}} = \sec\theta$$

(θ being the angle made by the diagonal with the vertical). Hence the stresses in the diagonals of portion m are equal to $\frac{n}{l}$ W $\sec\theta$, and in portion n they equal $\frac{m}{l}$ W $\sec\theta$.

First of all, the bracing is divided up into its component systems—in this case two—in order to render the result of the calculations definite. Thus,



The strains produced in the bars by the different weights, such as dead load, crowd or steam-roller are reckoned with in separate tables, and their results are summed up in the final table. If a weight be supposed to act at a joint of the bottom flange it will produce tension in the two bars which meet at that point, while the bars on either side will be alternately in tension and compression. This will explain the signs + and − which occur in the following tables, + representing compression, and − tension.

TABLE I.

Strains due to Dead Load (5 tons at each "node"). $\frac{W \sec \theta}{l} = \cdot 59$

(θ being 45°).

System 1.

Diagonals.	W_I	W_{II}	W_{III}	W_{IV}	W_V	Algebraic Sum.
1	+5·9	+4·72	+3·54	+2·36	+1·18	+17·70
4	−5·9	−4·72	−3·54	−2·36	−1·18	−17·70
5	−1·18	+4·72	+3·54	+2·36	+1·18	+10·62
8	+1·18	−4·72	−3·54	−2·36	−1·18	−10·62
9	−1·18	−2·36	+3·54	+2·36	+1·18	+ 3·54
12	+1·18	+2·36	−3·54	−2·36	−1·18	− 3·54

System 2.

Diagonals.	W'_I	W'_{II}	W'_{III}	W'_{IV}	W'_V	W'_{VI}	Algebraic Sum.
2	−6·49	−5·31	−4·13	−2·95	−1·77	− ·59	−21·24
3	− ·59	+5·31	+4·13	+2·95	+1·77	+ ·59	+14·16
6	+ ·59	−5·31	−4·13	−2·95	−1·77	− ·59	−14·16
7	− ·59	−1·77	+4·13	+2·95	+1·77	+ ·59	+ 7·08
10	+ ·59	+1·77	−4·13	−2·95	−1·77	− ·59	− 7·08
11	− ·59	−1·77	−2·95	+2·95	+1·77	+ ·59	0

TABLE II.

Strains due to Crowd (3·26 tons at each joint of flange). $\frac{W \sec \theta}{l} = \cdot 384.$

System 1.

Diagonals.	W_I	W_{II}	W_{III}	W_{IV}	W_V	Max. Compression.	Max. Tension.
1	+3·84	+3·07	+2·30	+1·54	+ ·77	11·52	
4	−3·84	−3·07	−2·30	−1·54	− ·77	..	11·52
5	− ·77	+3·07	+2·30	+1·54	+ ·77	7·68	
8	+ ·77	−3·07	−2·30	−1·54	− ·77	..	7·68
9	− ·77	−1·54	+2·30	+1·54	+ ·77	4·61	
12	+ ·77	+1·54	−2·30	−1·54	− ·77	2·31	4·61

System 2.

Diagonals.	W'_I	W'_{II}	W'_{III}	W'_{IV}	W'_V	W'_{VI}	Max. Compression.	Max. Tension.
2	−4·22	−3·46	−2·69	−1·92	−1·152	− ·384	..	13·83
3	− ·38	+3·46	+2·69	+1·92	+1·152	+ ·384	9·60	
6	+ ·38	−3·46	−2·69	−1·92	−1·152	− ·384	..	9·60
7	− ·38	−1·15	+2·69	+1·92	+1·152	+ ·384	6·15	
10	+ ·38	+1·15	−2·69	−1·92	−1·152	− ·384	..	6·15
11	− ·38	−1·15	−1·92	+1·92	+1·152	+ ·384	3·46	3·46

TABLE III.

Strains due to portion of 15-ton Steam Roller (7·25 tons at any one "node").

$$\frac{W \sec \theta}{l} = \cdot 855.$$

System 1.

Diagonals.	1	4	5	8	9	12
W_{I}	+8·55	−8·55	−1·71	+1·71	−1·71	+1·71
W_{II}	+6·84	−6·84	+6·84	−6·84	−3·42	+3·42
W_{III}	+5·13	−5·13	+5·13	−5·13	+5·13	−5·13

System 2.

Diagonals.	2	3	6	7	10	11
W'_{I}	−9·41	− ·86	+ ·86	− ·86	+ ·86	− ·86
W'_{II}	−7·70	+7·70	−7·70	−2·57	+2·57	−2·57
W'_{III}	−5·99	+5·99	−5·99	+5·99	−5·99	−4·28

NOTE.—The maximum strains are selected from this table for Table IV.

TABLE IV.

Summation of Strains from Tables I., II. and III.

C = Compression (strut).
T = Tension (tie).

Diagonals.	Strains from Table I.		Strains from Table II.		Strains from Table III.		Total Maximum Strain.	
	C	T	C	T	C	T	C	T
1	+17·70		+11·52		+8·55		+37·75	
2		−21·24		−13·83		−9·41		−44·45
3	+14·16		+ 9·60		+7·70		+31·44	
4		−17·70		−11·52		−8·55		−37·75
5	+10·62		+ 7·68		+6·84		+25·13	
6		−14·16		− 9·60		−7·70		−31·44
7	+ 7·08		+ 6·15		+5·99		+19·21	
8		−10·62		− 7·68		−6·84		−25·13
9	+ 3·54		+ 4·61		+5·13		+13·28	
10		− 7·08		− 6·15		−5·99		−19·21
11	0		+ 3·46	− 3·46		−4·28	+ 3·46	− 7·74
12		− 3·54	+ 2·31	− 4·61	+3·42	−5·13	+ 5·73	−13·28

The necessary sections for the diagonal bars are obtained from this last Table IV.

It may be observed, as a check to the accuracy of the work, that the strains in any two bars which meet on the unloaded flange are equal in amount, although opposite in sign. The ambiguity of sign in bars 11 and 12 shows that they are liable to both compression and tension.

The flooring used is shown in section in Fig. 7. For purposes of calculation of strength take one ridge and two half furrows thus , and consider it as a girder of 4 feet 6 inches span. The moment of inertia of the section works out to $25 \cdot 31$.

Then the moment of resistance $= \mathrm{M} = \frac{f}{d} \times \mathrm{I} = 70 \cdot 87$ inch-tons where

d = distance of extreme fibres in tension from neutral axis $= 2\frac{1}{2}$ inches.

f = allowed tensile stress per square inch for steel = 7 tons (assumed).

I = moment of inertia $= 25 \cdot 31$.

The moment of resistance is the sum of the moments of all the horizontal stresses in any cross section round any point whatsoever, and is equal to the bending moment.

The bending moment in this case is $\frac{w\,l}{8}$.

Where

$$\mathrm{W} = \text{weight distributed},$$

and

$$l = \text{span} = 4 \cdot 5 \text{ feet} = 54 \text{ inches}.$$

Then, by equating the moment of resistance to the bending moment, we have

$$\frac{\mathrm{W} \times 54}{8} = 70 \cdot 87$$

or

$$\mathrm{W} = 10 \cdot 5 \text{ tons}$$

distributed as the total distributed load that the girder can carry, i. e. $1 \cdot 7$ tons per square foot over the whole platform.

Appended is a memorandum of the tests of the plates, bars, &c., made at the works.

RESULTS OF TESTS OF STEEL PLATES, ANGLES AND BARS, made by the Staffordshire Steel and Ingot Iron Company, Limited, for Blake's Bridge, Reading.

Plate No.	Test No.	Dimensions of Piece.		Ultimate Stress.		Elongation on 8 in.	Remarks.
		Size.	Area.	Total.	Tons per sq. in.		
						per cent.	
	7232	1·05 × ·85	·892	25·0	28·1	28·7	$6 \times 6 \times \frac{7}{8}$
	7246	1·40 × ·61	·854	25·0	29·3	26·2	$6 \times 4 \times \frac{5}{8}$
2	6641	1·74 × ·50	·870	23·5	27·0	23·5	Plates.
11	6643	1·61 × ·37	·595	16·5	27·7	27·5	„
22	6645	1·74 × ·33	·574	16·1	28·1	25·0	„
34	6649	1·74 × ·36	·626	19·3	30·8	25·6	„
42	6653	1·74 × ·45	·783	22·0	28·1	30·0	„
	6401	1·60 × ·62	·992	28·6	28·8	30·0	$3 \times \frac{5}{8}$
	6412	1·74 × ·48	·835	24·6	29·4	27·5	$9 \times \frac{1}{2}$
	6417	1·30 × ·74	·962	26·0	27·1	31·2	$6 \times \frac{3}{4}$
	6419	1·47 × ·48	·835	24·6	29·4	27·5	„
	6432	1·30 × ·74	·962	27·1	28·2	31·2	$6 \times 6 \times \frac{3}{4}$
	6441	1·60 × ·48	·768	22·6	29·4	28·7	$7 \times \frac{1}{2}$
	6452	1·38 × ·51	·703	19·2	27·3	30·0	$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$
	6469	1·74 × ·47	·817	24·5	30·0	29·3	$3 \times 2\frac{1}{2} \times \frac{1}{2}$
	6644	1·18 × ·75	·862	25·5	29·6	31·2	$15 \times \frac{3}{4}$
	6655	1·18 × ·74	·873	26·0	29·8	27·5	$12 \times \frac{3}{4}$
	6714	1·19 × ·62	·737	22·0	29·8	28·7	$3 \times \frac{5}{8}$
	6727	1·74 × ·53	·922	26·5	28·7	30·0	$4 \times 4 \times \frac{1}{2}$
	6729	1·74 × ·54	·939	26·3	28·0	31·8	„
	6731	1·60 × ·50	·800	24·3	30·4	23·7	„

DISCUSSION.

The PRESIDENT said that the Members of the Society were very much obliged to Mr. Burrows for having given them so many points of interest to turn over in their minds. The subject of the paper had been treated historically, and the work described, although not very extensive, contained many points of interest. He moved that the thanks of the Society be given to Mr. Burrows for his paper.

The vote of thanks was carried by acclamation.

Mr. A. T. WALMISLEY said that Mr. Burrows had given a very good record of the work upon which he had ably fulfilled the duties of resident engineer. When he (Mr. Walmisley) was first informed by Mr. Burrows that he had been asked to prepare a paper on Blake's Bridge, he had grave doubts as to whether the work was of sufficient importance for the Transactions; but at the same time he thought that there were some points of interest which would lead to a profitable discussion, especially in connection with the way in which the parapet of the bridge was treated without any strain being brought upon

the ornamental cast-iron fittings. He thought that sometimes in large works they were apt to overlook minute details in the vastness of the work. Perhaps, therefore, there might be some use in considering a smaller work like that now described. The old bridge was erected in 1855, as appeared by the date which it bore upon a plate in the structure. It certainly was a very good piece of engineering for the time at which it was put up, inasmuch as the cast-iron vertical struts were simply wedged in, and not bolted or fixed by key cotters, so that they were able to take only a compressive strain. They were placed between the top and bottom flanges of the old girder. He (Mr. Walmisley) decided that in the new bridge he would convey the strains from the bottom flange to the top flange direct, without connecting the diagonals where they crossed in the centre, as was done in so many other cases. It was very evident that where they had an inclined strut going from the bottom to the top, and they connected the tie going in a cross direction, a load upon the tie tended to deflect the strut and induce strains, which prevented the calculation from being of so definite a nature as it was desirable to make it. In the Charing Cross Railway Bridge, to which allusion had been made, the struts had been so connected, and it appeared to him that this connection complicated the strains and made them less definite. One great reason for adopting the girder system in Blake's Bridge was that he wanted, if possible, to bring in the abutments belonging to the original work. The new girders were put completely outside the site of the old bridge. He was able to support the ends of the new girders upon independent piers which formed part of the extended abutment, and thus make use of the abutment of the old bridge in the abutment of the new. Therefore the weights were carried by the roadway, and communicated by the cross girders, and so to the main girders. The main girders were supported by the four piers, one at each of the extremities. As to the camber of the cross girders, he had to provide for the girder being strong enough in the centre, and to avoid any increase in the amount of metal in the centre of the new flanges; by making the girder deep in the centre, he had been able to get the proper camber for drainage. The cross girders were suspended from the main girder. It was not always advisable to suspend cross girders in that way, but in this case he wanted to avoid making the parapet of very great depth, and, at the same time, to use the main girder as a parapet, only adding a timber coping. The cross girders were bolted up as described. The cross girders which came down as shown in the diagram were stiffened with brackets upon both sides, and bolted up to the main

girder, and an ornamental casting, made as thin as possible, was put over the bracket-plate to give effect. To have made the main girder deeper and have attached the cross girders at the sides instead of suspending them, would have brought the apices at the meeting of the lattice bars further apart, and the cross girders would have been further apart.

Mr. Burrows in the paper had described the tests as they were specified. It was required in the case of the cast iron that the deflection should not be less than $\frac{5}{16}$ of an inch. He might mention a rather amusing instance which came under his notice in another case in which he had specified the same test. The drawings were taken to an eminent firm of quantity surveyors, and, thinking to be extra clever, they departed from the specification in their bill of quantities, and specified that the deflection in the cast-iron piers should be not more than $\frac{5}{16}$ of an inch. They thought that they had improved the specification. Of course, according to the term which they made use of, there might be no deflection at all. As stated in the paper, the bridge was opened two days before the two months arranged for had expired. The vehicular traffic was impeded only for two months and a half, and it was stopped for only two weeks during the progress of building the south abutment to enable a culvert which discharged into the river to be diverted, and Messrs. Huntley and Palmer's water supply from the river to be sustained.

Mr. W. P. Morison said that Mr. Walmisley stated that he was not altogether favourable to suspended cross girders, and he (Mr. Morison) endorsed that remark. Generally speaking, suspended girders were an objectionable form of construction, and he would not adopt them except in a case of imperative necessity. He thought they might have been avoided in the present case. If the main girders had been made a little deeper the cross girders might have been carried upon the flanges, and that would probably have led to some economy in the metal of the main girders. It was not considered objectionable to have a deep girder. The Americans indulged in girders of extreme depth in some of their great works. With regard to the rolling load adopted for the calculation of strength, it was the general practice of his firm in designing road bridges to adopt for the loading traction engines which gave a load of 14 tons on one pair of wheels and 8 tons on the other pair. Some railway companies adopted even more severely concentrated loads than that. He should not like to adopt a loading of anything less than that derived from such a traction engine as he had indicated, and he should also consider it necessary to assume a train of such engines going over the bridge. They

had to provide for the greatest possible load in estimating strength. It might be said that the bridge should be covered with traction engines, but of course there was some limit as to what should be brought upon them. He should certainly consider it necessary to assume a train of heavy traction engines on one side of the bridge, and the rest of the bridge covered by a crowd, which he did not think would weigh more than 112 lb. to the square foot. He observed that for the flange strains the parabola had been taken. That was, of course, perfectly correct with a continuous web girder, but he did not think it was so in the case of a triangulated girder. The increment of flange strain at the apex of each pair of diagonals was the load multiplied by the tangent of the angle of inclination with the vertical, and it did not give quite the same curve as the parabola. He thought that the parabola would in some cases give rather an excessive strength, so, at all events, it was on the safe side.

The attempt to combine ornamental design with engineering construction seemed to be very successful. The idea of attaching the ornament to the girder so as not to interfere with the deflection in any way was excellent, and it was a point which perhaps would not always suggest itself in such a case. It had been said that felt was the best bedding for girders of light weight, but it seemed to him a very poor material to put between an iron girder and a masonry abutment in a work which should be regarded as a structure which was to remain in perpetuity. He did not see why, if lead was the best bedding, it should not be used with a comparatively light girder as well as with a heavy one. He believed lead to be far preferable to felt. He should have liked to hear what paint the bridge had been treated with. That was a question which had led to important discussions at different engineers' meetings. The question of the preservation of iron was one which ought to receive very great consideration from engineers. The paper was otherwise a very complete one, but he missed any reference to the measures which had been taken for preserving the life of the work. No arrangement seemed to have been made for carrying off any water that might get through the bridge. He apprehended that it was proposed to make the bridge watertight by its construction. He did not gather whether any of the troughing had been filled with what was usually called bituminous or tarred concrete. He thought that if the troughing was properly treated with tar, and filled with bituminous concrete, and then covered with the best asphalt interleaved with felt in a proper manner, such treatment would be the most satisfactory method of making the bridge watertight. If such

a system was employed it would obviate the necessity of having gutters and down-water pipes, which got choked and led to great inconvenience.

Mr. J. W. Wilson, jun., said, they should bear in mind that it was not altogether the dimensional magnitude of an engineering structure, or the actual expenditure upon it, which formed a measure of its importance, and it was, he thought, a useful thing for the Members to see how a work which was in some respects comparatively small in magnitude might yet be an example of good engineering. Certainly there was not too large a supply of good works upon Bridge Design and Construction, and it would be distinctly an advantage to the Society to have this paper in their Proceedings, with its accompanying tables, which were very complete, and would be instructive to many of the Members. The allusion to the old bridge, in which there was a combination of wrought and cast iron, was interesting. As far as he could gather, the cast iron was used for the compression portions of the girders, which was a very objectionable system. Engineers of the present day would not think of combining cast and wrought iron in that manner. Many of those present, however, had doubtless often travelled over an important railway bridge in which the upper portion of the girder was constructed in that way, though he did not think that many were aware of it. The bridge was still standing, but he said "still" with some apprehension, and he would not mention its name. The combination of cast with wrought iron as a matter of ornament was a different thing altogether. Of course the size of a work was to be considered with reference to the use of ornament. If they had to erect such a structure as the Forth Bridge, they would not attempt to ornament it. But in the case of works of small size it was to be regretted that a little more attention was not paid by engineers to the matter of ornament. In the work at the Calais Docks there were some girders which were very much improved in appearance by attention to some details of the ironwork, though, of course, it involved some extra cost. He should be glad if the author would tell them what was the actual extra outlay for ornamenting Blake's Bridge. Upon a recent occasion he had been obliged to refute as far as possible the charge made by previous speakers that engineers put up ugly structures without any regard to appearance. There were many fine roofs, bridges, &c., of an ornamental character in London and elsewhere; he hoped there would be many more. The Charing Cross girder was referred to in the paper, and it might not be generally known that if any one attempted to analyse the strains in that girder he would find they did not work out as would be expected. A

reference to the paper which was read before the Society at the time of the construction of the bridge would show that the verticals were inserted after the calculations had been made, to give some extra strength by direct connection between the top and bottom elements of the girder. He agreed with Mr. Walmisley that the diagonals should cross each other without connection, otherwise when deflection of the girder occurred they would find one portion of it pulling another out of the straight line, which was very undesirable. He hardly agreed with Mr. Morison about the suspension of the cross girders, but he agreed with him to some extent if the bridge was one of magnitude. They must, however, take each particular case and consider it on its own merits. Blake's Bridge was a small one, and it would appear to be more advisable here to suspend the cross girders than to make the whole of the main girders of extra depth at extra expense, so as to provide parapets, &c., simply that the cross girders might be rested upon them instead of hanging beneath. In the present instance the suspension of the girders gave an opportunity for the introduction of some very ornamental work.

The paper gave some interesting information with regard to pile-driving. Perhaps the author would state what length of the upper portion of the oak piles was taken off in order to ensure that what was left should be thoroughly sound. That was one of the points which the engineer had to consider in driving piles. However careful he might be to have a heavy ram with a small fall, still the upper portion became crushed to some extent. He (Mr. Wilson) would like to know how much less was spoilt of an oak pile than of one of softer material. Scouring was a point which certainly ought to be allowed for to a considerable extent in the driving of piles for the foundations of bridges. With regard to the factor of safety shown on the board, there appeared to be a good deal of variation between one-half and one-sixth. Certainly a large factor of safety was wanted when there was any possibility of scouring. When the River Thames was narrowed as it was by the construction of the Thames Embankment, the scouring that was produced laid bare the piles beneath the piers of one of the bridges on the river, and engineers were for a time undecided as to what they should do to put the matter right. At Portsmouth he had been confronted with a difficulty pointed out by Major Raban, the Civil Engineer in charge. Here some old piles beneath the dock wall had been laid bare, not through scouring, but through the dredging which had become necessary in consequence of the increasing draughts of the vessels which had to be taken in. The result had been that the piles

had sunk, and some of the basins and walls had been rendered perfectly useless.

The question of paint was certainly a very important one, and it seemed to him that engineers occasionally fell into the error of covering their work, so that they could not get at it to repaint it. Of course, in a work of magnitude, such as the Tower Bridge, in which the sections of metal were very big, and which would last for a great length of time, there would be probably no objection to the structural work being built in with ornamental stone, so that it would be more or less inaccessible. Sir John Fowler and Sir Benjamin Baker, in one of their reports on the Forth Bridge, mentioned a significant fact. In that bridge, some of the lower work was covered with asphalt, and it was found that, instead of being a protection, it acted as a concealment, and that underneath the asphalt there were processes going on which they had not anticipated. They therefore reported in favour of the removal of the asphalt, in order that all parts might be accessible. He (Mr. Wilson) thought that accessibility in engineering work was one of the most important conditions.

Mr. W. Schönheyder said he thought that the work which had been referred to for ascertaining the sustaining power of piles was an American book. He did not know why the engineers of this country should go to the other side of the water for information on bridge building. Although they could not put up bridges as quickly as the Americans, they might pride themselves that their bridges did not fall down so quickly as those of the Americans. He noticed that in *Engineering* of April 28th this year, the Western Pennsylvania Engineers' Society describe the testing of some full-sized bridge members, duplicates of actual members in use; out of nine tests made, seven failed for the several reasons there given, so that a great number of faults of construction had been found out, and great care should be exercised in copying their work; it would be quite enough for English engineers to go upon their own formulæ and experience. He noticed in the formula on the board that the extreme load in tons, which a pile could support, was supposed to vary as the cube root of the height of the fall, that was to say, that if they gave a ram eight times the fall of another, the load which the pile thus driven could carry should not be more than twice. He did not quite see the rationale of that, unless it was to be supposed that a much greater height of fall crushed the pile and damaged it more or less. He had seen a great many English formulæ for the carrying load of a pile, and it was always taken in direct proportion to the fall: that seemed to be much more reasonable.

With respect to the cross girders, he rather favoured their being attached to the upper flange, because it enabled a greater depth of main girder to be got in with possibly cheap construction. But suppose they were put underneath, might not the ends have been much shallower? He noticed that the cross girders were attached to the main girders by bolts. He did not think that that was at all a desirable method. It was quite impossible to secure a bolt as tightly as a rivet. A bolt might become loose, or its threads might strip or rust off. He did not know why bolts should be preferred to rivets, they certainly were not any cheaper. He did not see the use of the side brackets which were to act as a kind of stiffener. There was a direct downfall when cross girders were hung from main girders, and he saw no necessity for the brackets. The main girder was not very long, but he should like to know whether there was sufficient provision for sideway stiffness of the top boom. No gusset plates were put in to stiffen the top boom sideways, possibly the width of it was sufficient in proportion to the length. The pipes which had to be carried by the bridge were threaded into the cross girders, and he did not see how it would be possible to repair them. The arrangements for bolting on the ornamental brackets, so as to prevent the cast iron from being subjected to any of the stresses to which the steelwork was exposed, was very ingenious, but he thought that the way in which it was carried out, to a certain extent frustrated the intention, for there was no provision to prevent a very "careful" fitter from screwing the bolts up so tightly that the cast iron was unable to move. The bolts ought to have been collar studs firmly fixed to the steelwork, and arranged in such a way, say by a distance piece and washer, that a fitter could not possibly screw the cast iron up tightly. One very important part of the bridge appeared to him to be inaccessible to painting. That was the upper flange with the wooden handrail that covered it. Perhaps the author would state whether that was removable or not. The paper was a very interesting and useful one.

Mr. H. O'Connor said he had recently had to superintend the driving of some 400 piles. The test he put upon the piles was certainly far in excess of that which would be given as the extreme load by the formula exhibited. Upon working it out roughly, he found that the weight of the extreme load should be 60 tons. In the case of the pile which he tested, he put on, in the first place, 100 tons, and this caused a sinking of about $\frac{3}{16}$ of an inch. It went down to that extent in the first 20 or 30 tons. It was simply a subsidence in the first place while the pile was taking its bearing. From the 100 tons he went on to another 20 tons, and the only difference was another $\frac{1}{16}$ inch.

With the 100 tons the drop was practically *nil* from the commencement. That would be nearly double the amount which would be given by the formula shown on the blackboard. As to the question of skin friction which Mr. Wilson raised, he (Mr. O'Connor) found that there was very little value in it. In some cases they would not pass the test in the ballast which was some 30 feet below the ground, and from 5 feet to 7 feet thick. But after they had once passed through that, they went down to the chalk which was some 80 feet. The difference was no greater after once they had passed through the ballast. The friction caused no stoppage in the rate of progress until they arrived at the chalk. They then pulled up, and stood the test which was required of them; but he did not think that the skin friction was of very much assistance, unless the piles were in ground which could stand the test in the first instance. In most cases the ballast was sufficient to withstand the test, which was four blows of a ton ram, falling 5 feet, and causing nearly a $\frac{3}{8}$ inch drop in the pile. He had recently had to take out some girders that had been bedded upon lead sheeting, placed between the wrought-iron and the cast-iron columns, and the lead seemed to have been impoverished, and both the wrought and the cast iron appeared to have deteriorated considerably, possibly by some electrical action, during the twenty-three years that the structure had been erected. It was questionable whether lead ought to be placed between wrought and cast iron. Of course the question of lead between wrought iron and stone, or steel and stone, was another matter. He was not able to say what the effect would be in that case.

Mr. W. H. Holttum said he did not see the slightest reason why the cross girders should not be suspended if they were properly suspended. One speaker had referred to the question of bolts for their suspension. If the suspension was carried out as it was to his knowledge in some large bridges, there would not be, as far as he could see, any objection to it; that was to say, if a plate was brought down to the end of the cross girder, and riveted to it. In a bridge like that under discussion, and which was a well-designed and carefully thought-out structure, it was a very good provision to suspend the girders. With regard to the pile-driving which had been referred to by Mr. O'Connor, who had evidently had much experience, he (Mr. Holttum) would like to know whether he had correctly understood that 14 tons had been put upon a 13-inch pile. With regard to the scouring to which Mr. Walmisley had referred, the provision that he had made was a very excellent one, namely, that of sheathing, with a concrete apron in front of it. The river Kennet was very rapid at times, and

liable to flood, and the scour would be very considerable. The author might perhaps be able to tell them whether he had any means or opportunity of judging how far the scouring action extended down into the bed of the river. He was glad to hear a discussion upon the methods of seating. The view taken with regard to the perishing of the lead was a new one to him. He had always thought that lead was used when they could afford it, and felt because it did not cost so much as lead. The felt, however, appeared to have received the greater favour in the discussion, and undoubtedly it was a fairly lasting material. It would not last for all time, but then he did not suppose it was expected that steel structures would last for ever.

Mr. MORISON observed that his remarks as to a suspended cross girder might have been a little misunderstood by some present. Of course, his chief objection to them was based upon putting the bolts and rivets in tensile strain instead of in shearing strain. He knew many excellent structures put up by high-class designers with suspended cross girders. In those cases it would be found that the girders were carried on rivets in shear, and not in tension. The same remark applied to bolts.

Mr. H. CONRADI, referring to the question of the suspension of the cross girders, said that, as far as his experience went, it was always preferable that the cross metals should be connected with the main ones, and not be suspended. In light girders for a road of a width like that of Blake's Bridge, with such a short span, it might be otherwise; but usually the best way was to connect the cross girders with the main girders by gussets. He did not know whether any provision had been made for wind ties, or whether they were necessary. He had not heard whether this bridge was much exposed to the wind or not.

Mr. WALMISLEY said that the bridge was surrounded by high buildings.

Mr. CONRADI said, with regard to the strains, that Humber's handbook on Strains in Girders gave far better formulæ than were given in Trautwine's work. With regard to the seating of the girder, he wished to know whether it simply rested on the cast-iron bed plate, or was put on rollers, and whether it was necessary that such a short girder should have rollers. It appeared to depend upon circumstances. Sometimes short girders required rollers, and sometimes they did not. With regard to lead, it was the worst material for bedding that engineers had, especially with heavy structures. If heavy girders were laid on lead, the lead pressed into the underlying masonry of the bed and cracked the stones. It was far better to have a layer of felt, or some similar material. He spoke upon the authority of experiments made by Professor Unwin.

However, lead was preferred by some contractors, but they were wrong. Lead was affected by the season. When lead had been lying on its bed in the hot season it spread out, and in the cold weather it contracted, and the contraction was not equal to the contraction of the masonry and the stonework. The consequence was that the lead, having penetrated the fine fissures of the stone, cracked the stone, and pieces dropped out. For those reasons a soft material was certainly preferable.

Mr. S. J. Ball inquired what provision had been made for getting at the gas and water pipes which were carried by the bridge. He also wished to know what kind of joints were made in the gas and water pipes, whether spigot and socket, or lead, or what. He should also like to ask the author whether any difficulty was found in the navigation of the river during the construction of the bridge, or whether the navigation was suspended altogether.

Mr. Perry F. Nursey said he thought that the majority of the meeting would be strongly in favour of carrying the cross girders on the main girders rather than of suspending them from them, because the former method would give a much better bearing surface, and would not be trusting to bolts or rivets in tension. Mr. Morrison said he did not think a crowd would weigh more than 112 lb. per square foot. He (Mr. Nursey) thought 112 lb. was an ample allowance. Twenty-five years ago 80 lb. per square foot was considered sufficient, and was the factor used. As regarded felt *versus* lead, he was in favour of lead. Felt became dry, and it got disintegrated and ground up with the action of the expansion and contraction of the girders. No doubt there were objections to both materials, but he thought that lead was more appropriate in a bridge and would do better service. As to the question of watertightness, he considered the best plan was to provide fairly for the surface drainage of a bridge, and not to tax ingenuity to make the roadway watertight. It might be taken for granted that water would defy all complicated and delicate refinements, and would get through in some way or other. The traffic on the bridge would set up vibration which would soon create ways for water to creep through. The better way was to assume that a bridge would leak, and to provide against the drippings becoming a nuisance.

The President said that Mr. Burrows' paper had elicited a very full discussion. The various speakers had anticipated anything which he (the President) might have wished to say. With regard to the relative merits of felt and lead, his experience went to show that felt was the better material of the two. When lead was brought into contact with steel, an electrical

action was set up, as Mr. O'Connor had observed, and that seemed to destroy the steel. There was much in the remark as to the unequal expansion of the two materials, but, in any case, his opinion was that felt was the better material of the two for bedding the ends of girders upon.

Mr. Burrows, in reply, said that the discussion which his paper had elicited was very gratifying. The load that was placed upon the bridge for testing purposes was a 15-ton roller, the rest of the bridge being covered with a load of 1 cwt. per square foot. That far exceeded the maximum load which the bridge would be called upon to bear. Although the parabola was not theoretically correct for the curve of bending moments, it was all that was required in calculation for practical purposes. The trough flooring was filled in with cement concrete, six to one. Mr. Wilson had asked whether the cast-iron ornament added much to the cost of the bridge. The cost of it amounted altogether to about 60*l*. If the parapet had not been filled with that ornament, some other device would have been necessary to prevent children and animals from falling through. The foundation piles were all sawn off to the proper level, and in most cases left a very fair head. The factor of safety in the formula on the blackboard varied from half to one-sixth. Of course it varied according as to whether the pile was driven in rock or in mud. Trautwine said one-half where the pile was subject to tremors of any kind. If the cross girders had not been suspended, but placed upon the bottom flange of the main girders, the latter would have been much deeper, the cross girders would have been further apart, and would consequently have been made deeper. The whole structure would in fact have become deeper, which would have defeated the end in view, namely, keeping within the specified levels of headway and road surface. With regard to the scouring action to which Mr. Holttum had alluded, it was not so great now as formerly. Sewage works had been constructed just below the bridge, and the water was regulated and kept at a fairly uniform level.

Mr. Conradi asked what kind of floor had been put on the bridge.

Mr. Burrows said that the floor was of corrugated steel, 5 inches deep, of Messrs. Handyside's own section.

Mr. Walmisley said he should like to state that the diagram of strains in Fig. 12, and the calculations which accompanied the paper were entirely the author's own, and not a copy of his (Mr. Walmisley's) calculations. With regard to the main girder, it was desirable not to have the parapet too deep. It already looked a good depth. As to the cross girder connec-

tions, it must be remembered that, although the bolt connections were in tension, there were nuts at top and bottom, and there were a number of bolts connecting the bracket to the main girder which were not needed to connect the cross girder, and which all formed an additional factor of safety. With regard to the screwing up of the cast iron, Mr. Burrows, as resident engineer, saw that the bolts were not more than hand-tight. In his opinion as to the use of lead, he (Mr. Walmisley) was quite aware that lead and iron would act electrically if moisture be present, but not otherwise. If the iron was well painted, then corrosion would be impossible. Mechanically, lead was much better than felt. Felt was perishable and only suitable where the weight was not sufficient to crush the lead. Some engineers sandwiched the lead between felt under bearings, but his practice led him to prefer plain lead wherever the reaction at the point of support was comparatively great.

Fig. 1.

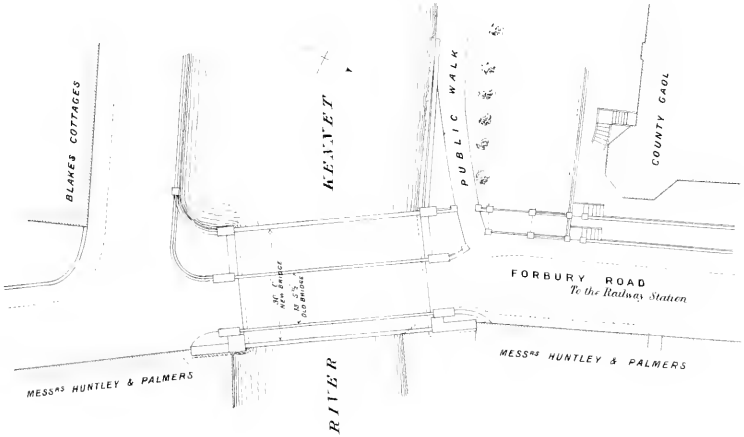


Fig. 2.

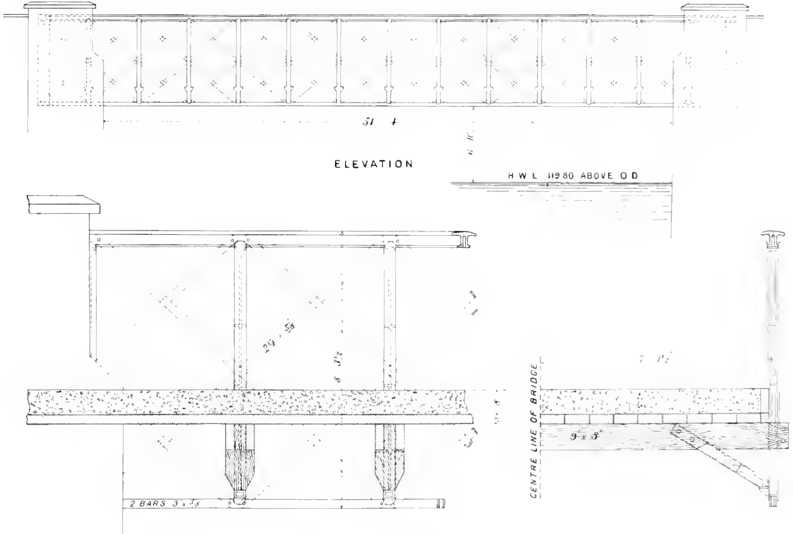


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Fig 3.

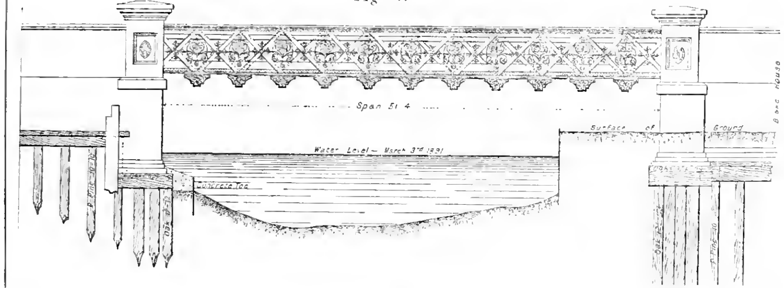

Fig 4.

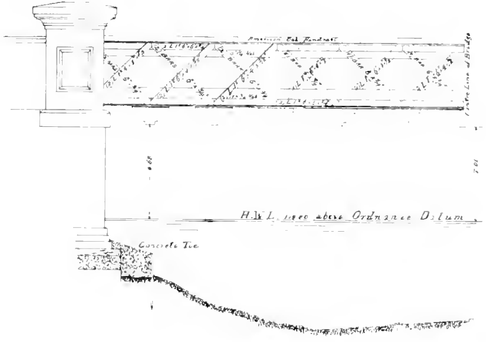

Fig 5.

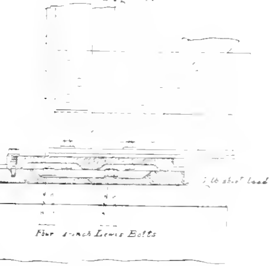

Fig. 6.

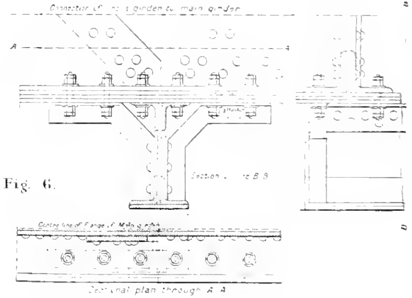

Fig. 7.

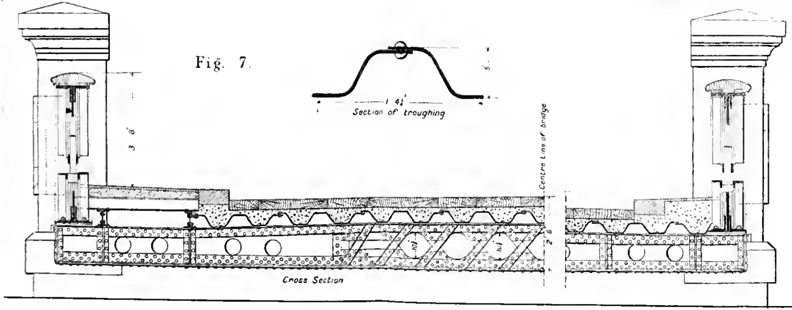

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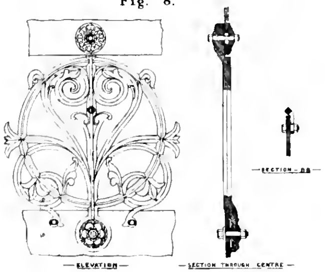
Fig. 8.



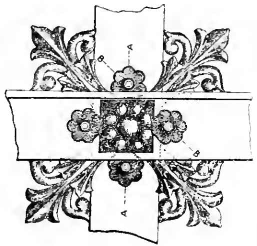


Fig. 9.

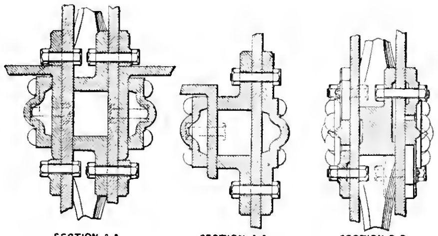


Fig. 10.

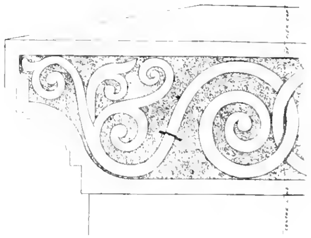
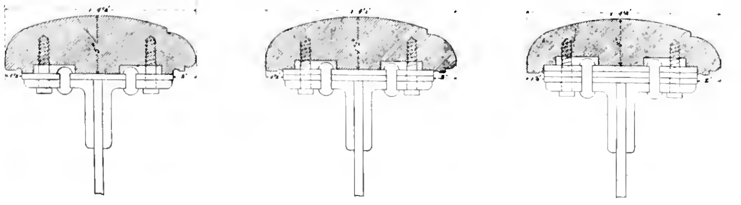


Fig. 11.



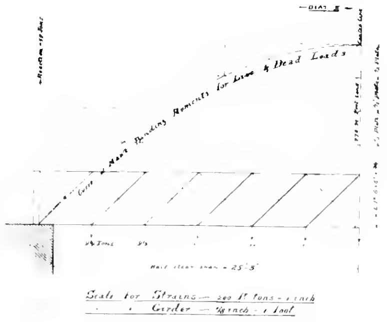
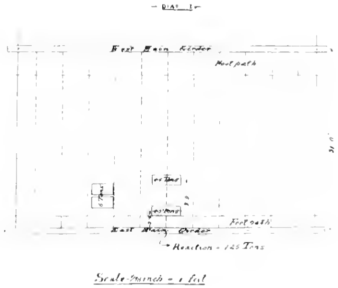


Fig. 12.



E. & F. N. Spon London & New York

June 5th, 1893.

GEORGE A. GOODWIN, VICE-PRESIDENT, IN THE CHAIR.

HYDRAULIC LIFTS.

BY ROBERT CAREY.

HAVING been engaged for many years in the construction and working of lifts of various kinds, the author proposes to place the results of his experience before the Society in the hope that the information conveyed may be of practical use to the Members. Although he proposes dealing mainly with hydraulic lifts, he thinks it desirable to introduce the subject by a brief reference to lifts of other kinds and of lighter character. He need hardly point out that there is an almost endless variety of hand-power lifts, and lifts which are actuated by belting from pulleys or shafting. The latter are generally constructed with worm and wheel gearing, there being three pulleys on the worm shaft, the centre one being half the width of the others, and keyed on to the shaft, the two outside pulleys running loose. There are two belts for driving, one open and the other crossed, and as the open or the crossed belt is brought on to the centre fast pulley, the lift is driven up or down. When the two belts are both clear of the centre pulley, the lift is at rest. The balance weight should be considerably heavier than the empty cage, so as to divide the work. Some engineers object to worm and wheel gearing on account of the loss of power by friction, but the worm and wheel has the great advantage that it will not allow the loaded cage to run down. There should, however, be a small brake on the worm shaft applied automatically when the two belts are on the two loose pulleys, clear of the centre pulley. The office of the brake is to cause the lift to stop exactly at the same place, when the belts are struck off by the automatic stops at the top or bottom of the travel of the lift.

There is one form of power lift which has not had the extended use that might have been expected, considering it has been successfully working for many years. This is the continuous passenger lift, which is constructed with a number of

cages attached to powerful steel pitched chains, at equal distances apart. They are kept continually moving, and hence the name, the cages always ascending on one side of the well-hole and descending on the other. They move at a slow rate of speed, so that passengers may step in and out of the cages as they pass the various floors; and, with a very little practice, one can enter or leave with perfect ease. There is no waiting for this lift, as there is always a cage going up or coming down ready for the passenger to step into. No attendant is required, except to look after the driving engine. The continuous lift might be driven by an electric motor, and would make a good form of electric lift, the motor requiring very little attention.

The electric lift has recently been brought into notice in consequence of the facility with which this form of power can now be obtained, but almost of necessity they must have worm and wheel gearing, otherwise the motor has to be very large so as to run slowly, and the cost of the large motor is nearly prohibitory. There are other objections. It is very difficult to get the worm and wheel so truly cut that the cage moves perfectly smoothly, so that slight waves of motion are felt. Further, it is doubtful whether the electric lift can ever be quite as safe as the hydraulic lift, and safety is an absolute *sine quâ non* in all lifts, particularly those for passengers. For these reasons the author is strongly of opinion that it will be long before electric power can compete successfully with the almost perfect application of hydraulic power for passenger use. Lifts are becoming more and more a necessity every day; they are not now regarded as luxuries, as they used to be not many years ago, but they have taken their place as a labour-saving appliance of great utility, and in a great many instances they are absolutely indispensable.

Of all lifts the most important is that used for passengers, and more attention has naturally been bestowed upon each detail connected with these lifts than upon the details of other kinds. The failure of any important part of a passenger lift may be attended by a serious accident involving loss of life, therefore great care has to be taken that all parts are of ample strength for the work demanded of them. This, of course, is so in all machine design, but where life is directly dependent upon it, special care must be exercised, and many parts may be duplicated simply with this object in view.

The author ventures to say, without fear of contradiction, that at present no mode of actuating a lift surpasses, or, in fact, equals that of water under pressure. It may be open to discussion whether high pressure or low pressure is superior. High pressure, it is assumed, is obtained by pumping water

into an accumulator loaded to give the desired pressure, and low pressure by gravity from a tank fixed at some altitude. Both systems have their peculiar advantages and disadvantages. The high pressure has the advantage that the machines actuated by it are comparatively small, which is a greater advantage than might appear at first sight. The pipes also are small, and can be run without attracting attention in positions and places where the large pipes necessary for the low pressure would be most unsightly and almost inadmissible; and where, as in most parts of business London, the high-pressure water can be obtained from the Hydraulic Power Company's mains at a very reasonable charge, the high pressure is far the best. But although there are a few other towns fortunate enough to possess the same facility, such as Liverpool, Birmingham, Hull, &c., yet there are many more which depend upon the low pressure from the ordinary street mains, or must produce the pressure for themselves by pumping either into an accumulator or into a tank, and the question has to be decided which is the best. If there is only one lift to be worked, then in most cases it is preferable to pump into a tank placed as high as possible. If many machines have to be driven, then an accumulator and high-pressure pumps are to be preferred. But each case must be considered and decided separately, sometimes one and sometimes the other system being best suited for the case; no hard and fast rule can be laid down as to which is the best in all cases.

The advantages of the low-pressure system are quietness, and that when a tank is used for the water supply, it can be large enough to hold sufficient water for the lift to make several trips after the pumps have stopped working. The disadvantages are the large space occupied by the machinery and pipes, and their unsightliness, also the extra cost due to their size. On the other hand, the cost of the high-pressure pumps and accumulator would often be more than that of the low-pressure pumps and tanks, including the larger pipes and machines. Both systems will work satisfactorily. In some cases the low pressure tanks and pipes are fitted with fire hydrants, and afford a certain amount of protection against fire.

Some idea of the advantage of the Power Company's high-pressure water may be obtained by the following simple calculation: Their charge is 20*l.* for 100,000 gallons of water used in one quarter, the pressure is at least 700 lb. per square inch, and the energy stored in the water amounts to about 1,610,000,000 foot-pounds. 20*l.* would pay for 600,000 gallons of town water at 9*d.* per 1000 gallons, a fair average price, and assuming 50 lb. pressure per square inch would represent about

690,000,000 foot-pounds; there would therefore be a gain of 920,000,000 foot-pounds by using the Power Company's water, or a saving of about 57 per cent.

There are very many kinds of hydraulic lifts, but there are two broad distinctions, viz. the direct-acting and the suspended. The direct-acting has the cage or car thrust up by a ram beneath it, while the suspended has the cage pulled up by ropes or chains from above, and it is impossible to say which system is the better. For low travels no doubt the direct-acting is generally the better, but for very high lifts it is questionable whether the suspended lift is not the safer as well as the better, for other reasons, paradoxical as it may sound. There is little doubt but that the suspended lift is safer than the direct-acting lift, having the weight of the ram and cage counterbalanced by ropes or chains attached to the cage, and passed over sheaves at the top of the shaft and down to the balance weights. The cage and ropes, as well as the overhead sheaves, are subjected to much greater stress and strain in this form than in the suspended lift, because of the great weight of the ram which has to be balanced as well as the cage, the weight of the cage only having to be balanced in the suspended lift.

For moderate heights of travel there is no safer or better hydraulic lift than that known as the hydraulic balanced direct-acting lift. In this lift the weight of the cage and ram are balanced by a separate machine, called the balancing cylinder. The water actuating the lift never enters the lift-cylinder at all, but acts on the actuating ram of the balancing cylinder only. There are several kinds of balancing cylinders, but they all practically consist of a displacement or balance ram, the displacement of which is equal to the displacement of the lift ram. Weights are added to the displacement ram until the pressure created is such that the weight of the empty cage and lift ram will just descend, overcoming friction and raising the displacement ram with its weights. The water contained in the lift cylinder and balancing cylinder oscillates between the two cylinders: when the lift is up it is in the lift cylinder, when the lift is down it is in the balancing cylinder, means being provided for making up any loss of water through the stuffing boxes. The water, in fact, performs the part of the beam in a pair of scales: the actuating water, when admitted through the controlling valve, acts on the actuating ram, exerting a thrust on the displacement ram, increasing the pressure beneath it to the necessary extent to raise the weight of the lift ram, cage and live load.

The object of the balancing cylinder is to obviate the use of the balance weight attached to the cage by chains or ropes, to

get rid of the overhead sheaves, and to reduce the quantity of water used to the smallest practicable amount. In the case of direct-acting lifts working from the Hydraulic Power Company's mains, the one great advantage is the reduction of water used, as the pressure of 700 lb. on the square inch would in almost all cases be more than enough to raise the weight of the ram and cage with the maximum live load without any mode of balancing whatever, but a lift without balance (as the ram must be large enough in diameter to give strength as a column) if worked much would use such large quantities of water that the cost of working would be almost prohibitive. For instance, if we take a lift of 50 feet travel to raise a load of say five persons and attendant, or about 9 cwt., making 200 trips per day, the ram for this height must not be less than $3\frac{1}{2}$ inches diameter, and would use about 21 gallons per trip, which would make 4200 per day, or 327,600 gallons per quarter, and would cost, according to the Power Company's charges, somewhere about 45*l.* If, however, the same lift be provided with a balancing cylinder, it would only use 8 gallons per trip, or 1600 gallons per day, or 124,800 gallons per quarter, and the Power Company's charge would be 22*l.* 16*s.*, showing an annual saving of about 88*l.* 16*s.* by the use of the balancing cylinder. It is therefore well worth the extra first outlay. But even with the balancing cylinder, as now constructed, the same amount of water is used to raise a light load as a heavy one; the maximum amount of water is always used, although the minimum load may be raised. To construct the balancing cylinder and other parts so that a proportionate amount of water should be used according to the weight raised is perhaps the only direction in which the direct-acting hydraulic balanced lift can be much improved.

Great expense is sometimes incurred in order to balance what is called the loss by protrusion, that is, to equalise the lifting power throughout the entire travel, for unless some means is provided for this, the direct-acting lift will start with a much heavier load than it will carry to the top of its travel; for as the lift ram protrudes farther and farther out of the cylinder, the pressure of water acting on its bottom end diminishes according to the depth. In other words, it loses power exactly in proportion to the weight of water necessary to fill the space before occupied by the ram; therefore if the ram displaces 50 gallons of water, it would lose about 500 lb. of its lifting power in ascending to the top of its stroke, and must be designed to start with this extra power, hence the loss. In the old form of direct-acting lift, with balance weights attached to the cage by chains passing over top sheaves, the weight of the

chains is made to perform this office and equalise the power throughout the whole travel. But where the balancing cylinder is used some other method must be adopted if the protrusion is balanced at all. In very high lifts it is almost a necessity, on account of the great loss of power there would otherwise be, and the extra amount of water that would be used. This does not, however, apply to low-pressure balanced lifts in the same degree as to high-pressure ones, because in the low-pressure lifts the weight of water necessary to actuate the lift may be made to nearly or quite neutralise the loss by protrusion. But this cannot be done with the high-pressure lift, and therefore other devices have to be resorted to, such as enormously heavy chains made of cast-iron blocks for links attached to the moving cross-head of the balancing ram, or immensely heavy levers or moving weights so constructed as to gradually increase the weight pressing on the balancing or displacement ram, thus increasing the pressure in the lift cylinder, as the end of the lift ram rises higher and higher, keeping the same pressure always on the bottom end of the ram, no matter in what part of the cylinder it may be. Some of these arrangements for balancing the protrusions are very costly and occupy a large space, the only justification for the extra complication and expense being the extra saving of actuating water, but this generally amply repays the outlay. The economising of water is a very important consideration, as it is a continual saving in the cost of working. This point will be more closely examined later on, when the author describes a system in which a proportionate amount of water is used according to the load lifted.

Direct-acting lifts without any overhead sheaves or ropes, but balanced from below, have been patented and made by the author, but these are suitable only for low pressures. They are quite as safe as the direct-acting lifts with separate balancing cylinder, the power is constant throughout the stroke, and no space is required other than that necessary for the lift itself. The construction is simple and comparatively cheap, and is shown by Fig. 1. The cylinder is made of the diameter or area necessary to give the lifting power calculated as the diameter of the ram in the ordinary old form of direct-acting lift. It is, therefore, smaller by the clearance round the ram than the old form, but it is bored the whole length. The ram is made of steel as small as strength will permit, and a piston is attached to its bottom end, the cage being secured to the top. The weight of the ram and cage is balanced by a weight working up and down close to the cylinder in the well, and attached to the piston in the lift cylinder by means of chains or wire ropes passing over sheaves fixed to the top of the cylinder. The pressure

water, after passing the starting valve, is taken to the bottom of the cylinder in the well by a pipe, and the exhaust is taken from the starting valve into the top of the lift cylinder, there being a large exhaust pipe from the top of the cylinder to the drain. It will be seen that the water is always in the cylinder; as the piston rises the pressure above diminishes, and as it descends the pressure above increases, thus equalising the power throughout the entire travel. The protrusion of the small ram is compensated for by the weight of the chains or ropes to the balance weight. This form of lift has been very successful for moderate heights, and is eminently suited for very low pressures of water, or where a very heavy load is required to be raised by a low pressure of water.

Suspended lifts, on account of their greater cheapness, and their not requiring a well and cylinder sunk in the earth, are becoming more common than they were a few years ago. They have also been greatly improved in detail and construction. Chains have given place to wire ropes, the multiplying sheaves have been greatly increased in diameter with beneficial results, friction being reduced and the life of the wire ropes increased. For passenger use it is almost the universal practice now to suspend the cage by four wire ropes; for warehouse and goods lifts sometimes the owners are content with two, but very rarely one, except for very light loads. When there are four ropes, each one is of ample strength to do the work alone, and they are carefully examined at frequent intervals, say once every month, to see if there are any signs of wear, and directly such are detected the rope is removed and a new one put in its place. It is very difficult to imagine that there is much danger from the failure of the ropes, especially if there is a good safety apparatus. It has been suggested that where there is more than one rope to carry the cage, all the weight should be carried by one or the other, or others should simply run idle, merely being kept taut by springs, so that no stress or shocks can be communicated to them. By this arrangement it is claimed that the working rope alone will be liable to break; the others, having to bear no strains, will last much longer and be in a perfectly good condition long after the working rope is worn out. Should the working rope break, the others being comparatively unworn, will not be likely to break when the full weight of the cage is suddenly thrown on them. The author has had no experience, and does not know whether the ropes passing over the sheaves, without being loaded, would last much longer than the rope which had all the weight of the cage suspended thereon, but he thinks the probability is that they would. If so, perhaps this alone would be the most effectual

safety arrangement that could be applied, as it could not fail to act when the critical moment arrived. Another suggestion is that, in the event of the working rope breaking, the other rope or ropes may be made to exert all their strength to apply the safety cams. It would thus be almost impossible for the cage to drop, or, in fact, descend at all until the ropes were again made right, for assuming the ropes were so much worn that they were unable to withstand the shock of the weight of the cage being thrown on them, they would still be amply strong enough to pull the cams into action. This they must do before they take any strain at all worth mentioning, and, therefore, before any shock could affect them, they would only have to compress the springs that in the ordinary course of working kept them just taut, slightly more than before the working rope broke. That would be all the extra work required of them, for when once the cams were in contact with the wooden slides or runners, they would grip and hold fast, should the cage be descending, but if ascending they would only drag on the runners, but not bite. In the foregoing suggestions the principle is adopted that it is better to wear out one rope first, the others being kept in reserve to meet the contingency of the first rope breaking; if only one out of two or more breaks, no great harm is done.

There are many kinds of safety appliances in use for preventing the descent of the cage should the suspending ropes break, and it appears to be the fashion, so to speak, to have for passenger lifts four steel wire ropes, all doing equal duty, the safety apparatus being so constructed that, should any of the four ropes break, the others pull into action the safety cams or grips. In most of these arrangements, however, there is the fault that if all the four ropes were to break simultaneously, the safety gear would not come into action at all, and in some, if two ropes were to break at the same instant, the other two would not apply the safety cams at all. To meet this contingency, a fifth rope of less strength than the other four is provided, with the sole object of forcing the cams or grippers into action, should all the other ropes break. The multiplication of ropes, and the excellent safety appliances now in use, leave little to be desired in preventing accidents by the failure of ropes, but there is another inherent source of danger connected with suspended lifts, although happily a remote one, that is the failure of the overhead sheaves or spindles. Beyond making these of extra strength, it is not usual to take any special precaution; the only protection that could be suggested would be a strong floor or grid under the top sheaves, but this would be inadmissible in most cases on account of its unsightli-

ness and the obstruction of light. If, however, proper care is exercised in designing these parts and testing them before they are erected, very little danger need be anticipated from this quarter.

Whilst considering the question of safety, the author would like to draw attention to the construction of entrance doors or gates, for, though not actually part of the lift, they are so nearly allied with it that their consideration should not be parted from it. There are endless patents and proposals bearing on this one point, and, in the great majority, the idea seems to be that the doors or gates should open automatically when the cage approaches the level of the floor, and close automatically when it passes away. This may be done with advantage at the top and bottom floors only, because when the cage is approaching either of these floors, the intention is to stop there, but with the intermediate doors it is different. The cage may be going past the floor, when it is worse than useless to open and close the door as it passes. The intermediate doors should be opened by hand, and closed automatically when the cage passes away from the floor. Bolts can be so arranged that the doors can only be opened when the cage is level with the floor. Another good arrangement is to lock the starting rope when the door is opened, the lift cannot then be started until the door is closed. In this case, of course, the door does not close automatically, but has to be closed by hand before the cage can be moved.

The author would suggest that all passenger lifts should be examined, and a certificate given by a Government expert or inspector before they are allowed to be used for passenger traffic. Many lifts carry as many passengers during the day as a small line of railway in a country district, and, although the journey is short, if the lift is defective the danger may be great. The time occupied by the inspection would also be short, and tests might be made in the presence of the inspector, who should have power to withhold his certificate unless he considers the lift perfectly safe. This would ensure that passenger lifts, at least, should be well designed and constructed, up to a certain standard of excellence. The inspection of warehouse lifts, where persons are allowed to travel in them, would soon follow, and the makers of these lifts would so be compelled to turn out good work. Extreme cheapness should not be the first consideration for machines of this kind when absolute safety is of the utmost importance. True economy is not always the same thing as small outlay; a thoroughly good machine is generally cheapest in the long run, although it may cost more in the first instance.

One form of suspended low-pressure lift is shown by Fig. 2. The cylinder is placed vertically, and the water is introduced above and below the piston, by which means nearly an equal power is exerted throughout the entire stroke, as the pressure due to the height of water above the piston, and the sucking action of the column of water beneath the piston combined, would be the same in any part of the stroke if it were not for the small area of the piston rod, and this slight loss of power, as the piston descends, is generally more than compensated for by the weight of the ropes suspending the cage, passing over the top sheave from the cage to the opposite side. If it were necessary, by apportioning the size of the rod and the weight of the ropes, an exactly equal power could be obtained throughout the whole travel of the lift. This is a very good arrangement, and was introduced into use in this country some years since by the American Elevator Company; but, strange to say, this exact form was patented in this country by Harriott and Strode in 1802: the specification is not now in print, but it can be seen at the Patent Office Library. It is most carefully and accurately drawn, and describes this method of using a vertical cylinder. The author merely mentions this as showing how curiously before its time this invention was.

Fig. 3 shows an ingenious arrangement for balancing the weight of the ram and cage of a direct-acting lift, and at the same time equalising the power throughout the travel of the lift, and thus reducing the quantity of pressure water used. The displacement ram is weighted to nearly counterbalance the weight of the lift ram and cage as in the Ellington balance, but the actuating ram acts on the displacement ram through chains or ropes which coil on to cam-shaped barrels or fusees so that the downward pull on the displacement ram increases as it descends, thus increasing the pressure as the lift ram ascends, obviating any loss of power by protrusion. The balance was patented by Mr. Archer, and is manufactured by Messrs. Richmond & Co., and is an example showing the endeavours lift manufacturers are making to reduce the quantity of water used by their lifts to a minimum.

The author will next direct attention to a new system of hydraulic lifts and cranes, by which the quantity of water used is automatically approximated to the load raised. He is quite aware that multiple power machines have been made for a great number of years, that is, multiplying cylinders or jiggers, and also direct-acting lifts with more than one ram, a light load being raised by admitting water to one ram, a heavier load by admitting it to two, and so on. In some instances a ram

and piston are used when the pressure water is admitted to both sides of the piston, the annular space round the ram is in equilibrium, and the area of the ram only is effective. When the pressure water is admitted to the back of the piston, and the water from the annular space round the ram is open to exhaust the whole area of the piston is used, and the maximum load may be lifted. In other arrangements there are two rams, the smaller one working inside the larger, the bottom of the large ram being open. When a light load is to be raised, the large ram is held back by powerful claws or clips attached to the cylinder; when heavy loads are to be raised the large ram is released, and the two move as one. In this arrangement the combined areas of the two rams are not used, but the area of the large ram has to be sufficient of itself to raise the maximum load. All these methods, however, are more or less clumsy, and must take time to alter from one power to another. Therefore, on account of the time and trouble involved, the alteration is only made when a great number of light or heavy loads have to be raised in succession. The arrangement that looks most promising at first sight is that in which the power is increased by simply pulling the hand rope further on, the water being admitted to two rams, or the exhaust made from before the piston as before described. But there are difficulties in this, for instance, if a heavy load has been raised and the lift stopped, the rope only having been moved to the point at which it will stop when the heavy load is in the cage; when the load or part of the load is taken out, the lift starts on again until the rope is moved still further. This, of course, is a serious fault; it may, perhaps, be provided against, but the fact of leaving the attendant the option whether he will go on to the first or second power is not satisfactory, as, in order to save trouble, he will generally elect to go on to the second or largest power, although the machine was intended to save water and not trouble. Again, with this arrangement, there cannot well be more than two powers, whereas, to be a really economical machine, there should at least be three powers or grades, if not four or even more, and the discretion as to which grade should be used, should not be left to the person working the lift or crane, but should be automatically selected.

Successful attempts have been made to prevent the valve from opening to the second power or grade until a certain pressure has been obtained in the cylinder, indicating that the maximum lifting power of the first grade was nearly reached. The movement of the controlling rope or lever should be always the same, and the speed should be under control as well

as the stopping and starting in either direction. All these conditions, the author claims, are met and successfully carried out in his system, which he will now explain.

A lift which has now been working for some months, showing a great saving over the usual form in the water used, is fitted with two jiggers. One is practically the ordinary description, but the other is a four power machine. They are both constructed alike, so far as the multiplying power goes, that is to say they both multiply four to one, and are, therefore, both the same stroke. The ropes suspending the cage can be readily shifted from one machine to the other. One machine was first run for some time, and then the other, and the water used by the machines compared, and the actual saving shown in such a way that it is impossible to question the saving effected:—

Days at Work.	Trips made.	Passengers carried.	Galls. of Water used.	Galls per. Day.	Galls. per Trip.	Galls. per Pass.	Galls. used in 300 Days.	Cost from Power Company.
				Ordinary Jigger.				£ s. d.
275	54,493	103,308	393,400	1430·5	7·22	3·8	429,150	83 12 0
				New Jigger.				
134	27,291	54,849	80,700	602·2	2·95	1·47	180,660	46 0 0
				Saving effected by New Jigger.				
				828·3	4·27	2·33	248,490	37 12 0

The multiple-power jigger is shown by Fig. 4: it has one ram $3\frac{5}{8}$ diameter, pressed downwards by the water to raise the cage; this is assisted by weights added to cross-heads, which are sufficient without assistance from the pressure water to raise the cage with attendant and one passenger. There are three small rams fixed at the bottom which oppose the power of the large ram. The centre one of the three is 2 inches diameter and works through a stuffing-box into the interior of the large ram; the other two outside rams are $1\frac{5}{8}$ diameter each, and work into the two sides or tension rods, which are made of tubes to form cylinders for them. The two rams always act together as one. The action is as follows: For the first or lighter power the power-setting valve is so placed that the exhaust is made from all the cylinders or rams, the load is raised by the weight on cross-head alone. For the second power the pressure water is admitted into all the cylinders, the large ram is then opposed

by the three small rams, but as the area of the large ram exceeds that of the three small ones, increased lifting power is obtained. For the third power, the centre ram is opened to exhaust, the large ram then only has the two outside rams to oppose it. The fourth power has all the three bottom rams open to exhaust, when the full power of the large ram, assisted by the weights, can be used to raise the maximum load. To lower the empty cage, pressure water is admitted to the centre ram, all the others being open to exhaust, the weight of the cross-head, &c., is raised by this means; if a heavy load is in the cage no pressure water need be admitted, the weight in the cage raising the extra balance weight.

The principle of working the valves is very simple, and the details are not complicated, there being two valves—the starting valve and the distributing or power-setting valve. When it is wished to start the lift up, the controlling or starting rope is pulled down to the limit of its movement, the starting valve being thus opened in the usual way. At the same time the pressure water is admitted to the back of a small piston, which actuates the distributing valve which commences to travel forward. If there is a light load in the cage and the lift commences to move, the movement actuates a pawl, which is immediately dropped, and the further movement of the valve is arrested, the lift making the ascent on the first or smallest power. If the first power or grade is not sufficient to raise the load, the distributing valve continues to move from power to power until the right power is found, when the lift commencing to move, the pawl drops and arrests the further movement of the valve. There are various ways in which the pawl can be actuated. The one now in use is a small ordinary governor driven by a small wire rope attached to the moving head of the jigger. When the lift commences to move at the required speed, the balls fly out and lower the pawl; when the lift is stopped the pawl is raised again by the weight of the balls: the distributing valve always returns to its first or normal position directly the lift is stopped. The stopping of the lift, either on its ascent or descent, depends upon the starting valve in the usual manner, and has nothing whatever to do with the position of the distributing or power setting valve; and therefore the ordinary automatic stops on the starting rope, tapped by the movement of the cage, act as usual at the top and bottom of the travel to prevent overrunning.

Instead of the governor a small wheel was caused to revolve when the lift started, the pawl resting on the top of the wheel by a vertical pendulum stop, which was moved to one side or the other when the wheel revolved, and thus dropped the pawl

to arrest the further movement of the power setting valve. This was found very efficient in practice, but the neatest and most reliable way of actuating the pawl is by a small loose-fitting piston, causing the pawl to drop when the water commences to flow, and raising it again when it ceases flowing. It would be tedious to describe in detail the various means of arresting the further movement of the power-setting valve when the lift commences to move, but by doing this the great advantage is obtained that, however much the actual friction of the machine may vary, when the grade or power is reached that will do the work, then, and not until then, is the valve stopped from going on to the further powers. Therefore, when the jigger is repacked, and there is probably much more friction than there will be a few days afterwards when the packing has become free and easy, the working of the machine is not interfered with, although for a short time rather more water may be used to overcome the extra friction. It will at once be seen that this is a much more economical arrangement than any that could be devised, dependent upon the varying pressures created by the load in the cylinder, as in that case a larger margin or lap must be allowed to each power. That is to say, a large power must be started before arriving at the full power of the grade next below. If made to act too closely, constant readjustment would be required to suit the varying friction of the machine. With the arrangement described, each grade will work up to within a few pounds of its maximum power before the next grade is started, hence the great economy of water obtained.

There is another feature of importance to which the author would direct attention, and that is the extra safety obtained by the multiplication of the cylinders. In most cases they are smaller, and therefore less likely to burst than the cylinders of ordinary lifts. On the other hand, the bursting of any one would not leave the cage to descend uncontrolled. The second, and perhaps more important point, is that after the lift has once started no further power can be obtained. There is rarely, therefore, much spare power beyond that necessary to raise the load in the cage; consequently, should a person be caught between the floor of the cage and any part of the enclosure, instead of serious injury to life or limb, the probability is that the lift would simply stop. The author has continually tested this by catching hold of some protruding part of the enclosure, and bringing the lift to a standstill; and as, perhaps, one of the most frequent sources of danger is the jamming of a limb or the body between the cage and the enclosure or floor, anything that tends to mitigate this is of value, and may fairly be said to be a point of the utmost importance.

The arrangement, it is clear, can be adopted for direct-acting lifts with Ellington or other balancing cylinders. Fig. 5 shows a balancing cylinder with three actuating rams, the combined area being equal to the single ram usually provided, and Fig. 6 shows a suitable starting valve and power-setting valve. On the starting valve being moved back to make the ascent, it admits the pressure water through a pipe to the power-setting valve, and at the same time opens the exhaust from the back of the small piston which actuates this valve. The pressure water at once acts on the centre actuating ram, and if this has power enough to raise the lift the movement of the power-setting valve is stopped by a pawl, but should this ram be insufficient, the piston with the valve moves back slowly, first covering the port leading to the centre ram and then uncovering the port leading to the two outside rams, which act together. If the lift then moves the further movement is arrested by the pawl, but should these two rams not be sufficient then the valve moves on still further, opening the two ports leading to all three rams, giving the maximum power. When the lift is stopped, the starting valve is brought into the central position shown, and the pressure water is free to act through the small port and pipe on the back of the piston, thus driving the power-setting valve home to its normal or first position. In lowering, the valve remains in this position, the exhaust water from the two outside rams escaping through the retaining valve shown, or a separate pipe with a retaining valve may be employed so that the water need only pass through the starting valve in lowering. In cases where the balancing cylinder already exists, two or more small rams can be added, attached to the moving cross-head, and acting in the reverse direction to the existing actuating ram. If the pressure water is admitted into all three rams, the two small rams will oppose the large ram; but as their combined area should only be about two-thirds of the area of the large ram, the water is forced out of the cylinders and finds its way into the large cylinder, therefore only about one-third of the water is used. If the pressure water is admitted to only one of the opposing rams, two-thirds of the water will be used, and if it is admitted only to the large ram, the full power is obtained and the quantity of water used is the same as before the alteration. It is probable that instead of two rams four would have to be used, two always acting together on opposite sides of the cross-head, so as to give a central strain. If the balancing cylinder is over weighted, so as to raise the empty cage and the attendant without the use of pressure water at all, the lift may be made to lower loads over a certain weight, and store up the energy to bring up the empty cage with the atten-

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dant only in it, ready to lower another load; or the stored-up energy may be used to assist in raising the next load, therefore using a commensurate less amount of water. In some of the large stores in London, the passenger lifts are in constant requisition, the cage being nearly always full of passengers both up and down. In cases of this sort it would be easy to so design the machine that very little pressure water would be used. To accomplish this end, it would only be necessary to have either opposing rams or pistons, and the power-setting valve arranged to distribute the water to the right cylinders to drive up or down as might be requisite to deal with the load happening to be in the cage at the time. It is obvious that a ram might be employed instead of over-weighting the balancing cylinder, but this would involve returning the water into the mains, and this is objected to where the water is obtained from the Hydraulic Power Company's mains. The arrangement applies to suspended lifts with jiggers, as well as to direct-acting lifts with balancing cylinders.

The arrangements of stopping the further movement of the power-setting valve previously described, are perfectly good for a lift but quite unsuitable for a crane, the conditions of working being altogether different. When a lift is started, no further load is expected to be taken into the cage unless it is first stopped, but when a crane commences to raise a load resting on the ground it does not immediately have to raise the whole weight, but the weight increases as it is raised clear of the ground. Besides this, the loose chain has to be taken up before commencing to raise the load at all, therefore the same arrangement of stopping the further movement of the power-setting valve immediately the machine begins to move is impracticable for cranes. It is therefore proposed to interpose in front of the power-setting valve a graduated or stepped stop, moved up or down according to the load on the lifting chain. When there is no load, or only a light load on the chain, the first grade is interposed to prevent further movement of the valve; but as the load increases the stop is moved until it allows the valve to advance to the second or third power, and so on. The stop may be actuated by the tail end, or what is usually the fixed end of the chain, after having passed over the multiplying sheaves on the jigger or multiplying cylinder, or by arranging one of the leading sheaves over which it passes, on a spring or weighted lever, so that it is depressed more and more as the weight increases on the chain. The same action takes place when the goods are lowered, but in the reverse way. With very little extra cost the crane may be made to lower goods over a certain weight, and return the

empty chain ready to lower again without using any water at all, except the little sometimes necessary to raise the load clear of the floor before swinging it clear of the loophole. As in a great many cases as much weight has to be lowered by the crane as had previously been raised, this arrangement alone should save nearly half the pressure water used by a crane on the present system, which uses as much water to raise the empty chain as it would for the full load. The same remark applies with equal force to warehouse lifts, and the same advantage is claimed, that in lowering goods over a certain weight sufficient energy is stored up to return the empty cage without the use of pressure water at all. The energy is stored by raising a weight and not by returning the water to the accumulator or other source.

The next point of interest is the cost of production or manufacture. It is true there are several more parts in a multiple power jigger than in an ordinary single power one, and there are two valves instead of one. On the other hand, there is the advantage that the parts can all be smaller, and much may be saved by using smaller tools, and in the facility with which the smaller parts can be handled in the factory. Assuming a three-power machine, made with three solid rams, the total area of the three rams would only be equal to the area of the one ram in the ordinary machine. The total weight of the rams is therefore the same in both cases, but it is granted there is a little more cost in turning the three rams over the one large one. But the small cylinders can be made of wrought iron or steel tubes, and the three will not weigh more than, if as much as, the one large one, if made of the same material. The three small ones, however, will be quite as cheap if not cheaper than the one large one; they are certainly much easier to manipulate; the stuffing-boxes can be small castings screwed separately on to each cylinder or tube; the parts are all, therefore, much reduced in size. But the great advantage would be that these machines could be made and stocked, so that the sizes of the rams need not be different for every load the jigger is constructed to carry. The same machine would be used whether the lift raised a maximum load of say 5 or 15 cwt., or any intermediate load. It would not, therefore, be necessary to make a special machine for each job, as is the present practice. The length of stroke would merely be a question of cutting off the rams and tubes to the requisite lengths. All parts could be made to gauge and interchangeable, and it is anticipated that by making a few special machine tools, and by reducing the manufacture to the duplication of exactly similar parts, the cost would be little, if any, more than the present machine, which

can rarely be made in duplicate. There would be a very great advantage in being able to take the machine out of stock and start fixing it almost directly on receipt of an order, instead of having to wait while the machine was being prepared.

There are several inventions which have for their object the saving of water, or to some extent the using of the pressure water commensurately with the load lifted, and some of these arrangements are more or less automatic in their action. Mr. John Hastie, in his specification, No. 3561—1876, appears to be the first to propose anything in this way. He adopts the principle of opening a valve kept closed by a spring, when the pressure in the lift cylinder reaches a certain point. Mr. Robert Middleton, of Leeds, comes next, he also adopting the principle of actuating the valves by the varying pressures created in the lift cylinder by the various loads or weights to be raised. Then comes Mr. Thorpe, of the American Elevator Company, who likewise relies upon the varying pressures in the cylinder. There are also others who have worked in this direction, but they either rely on the varying pressure or on moving the valve further by the hand rope when larger power is required. Most of these arrangements would be affected by the varying friction of the pistons moving the valves, or the friction of the machine itself, and therefore cannot be made to work up to close upon the extreme limit of the power of the several grades, but a large margin of power has to be allowed, and for this reason the arrangements cannot be as economical as they otherwise would be.

DISCUSSION.

The CHAIRMAN, in proposing a vote of thanks to the author for his paper, said that the first point he had to notice was that of continuous lifts. He had seen only a very few of them at work in London, and he could not help thinking that they would not find favour with the public generally. They travelled very slowly, and the tendency of the age was a desire to travel quickly, even if the periods between the journeys were longer. He asked whether there was any safety gear fitted to continuous lifts. In connection with the driving of lifts by electricity, he thought that worm gearing was a very good and safe system when combined with the means of getting over the friction due to the end thrust on the worm. In 1889 he suggested that ball bearings should be used for this purpose, and he believed that it had been used since that time with very good results. As far as he knew, he was the first person to suggest it. The author stated that it was difficult to get a

worm and wheel so truly cut that the cage would move perfectly smoothly, but he (the Chairman) must in that respect differ from the author, for he thought that it was very easy. With regard to electrically driven lifts, there were some in Victoria Mansions. The water power from the Hydraulic Company's mains had been superseded by electro-motors, the cost of hydraulic power having been found to be very considerable. Water was now used over and over again, and the cost was thereby reduced. The electric companies now sold the current at a very much cheaper rate than they did formerly, and he would like to take this opportunity of impressing on them the advisability of selling current for motive power purposes at a special low rate, similar to what the St. Pancras vestry were doing, and for which they deserved the hearty thanks and approval of all those interested. He was pleased to see that the author stated that when the kind of lift to be used was in question each case must be considered and decided upon its own merits. Inventors were generally prone to recommend their own system. It was satisfactory to observe that the author was so open in his opinions as the paper showed him to be. The question of the wear of the ropes in passing over the pulleys when they were not doing any work was an interesting one, and he could not help thinking that a rope in such circumstances, doing no work, would last very much longer than when doing work. The author suggested that the overhead sheaves and spindles should be tested, but he (the Chairman) did not know how that could be satisfactorily done. He did not think that a mere dead-weight test would be satisfactory, for, as was well known, material alters its molecular structure by the constant fatigue which it undergoes while doing work. In connection with the figures which the author gave as to the relative consumption of water by his jigger and the ordinary jigger, he asked whether the ordinary jigger was a balanced one, for if not the comparison alone could hardly be made. The saving by the author's new jigger over the ordinary jigger was 57·9 per cent., but the substitution of the balancing for the ordinary jigger referred to in the paper gave an economy of 61·9, or 10 per cent. more. He should be obliged if the author would explain that. With reference to the power-setting valve, it was stated that the speed of the governor regulated the movement of the valve, but it seemed to him very possible for the lift to be so loaded that it would go up at such a speed as not to bring the governor into action at all as regards its controlling action, and thus not to bring about the economy of water which was desired. He should like to know at what speed the lift was running when the author was able to stop it

by putting his hand against an obstruction, as clearly if he could stop it the accelerating force in the machine producing motion must have been small. The question of conserving the water and utilising that on which the weight was lowered, was a very important one, and one which well deserved the attention of mechanical engineers. The conservation of energy applied to everything in which power was brought into use. Of course, theoretically, there ought to be no power required for lowering the weight, providing it was heavy enough to overcome the friction, and if the same weight or one slightly in excess was required to be raised, but very little power water should be used, and anything done with the view of lessening the consumption of the water would be readily approved, both by suppliers and consumers.

The vote of thanks was unanimously accorded.

Mr. Henry Adams said that, as an old hydraulic hand, he had been very much interested in the paper. Twenty years ago he was acquainted with almost every individual hydraulic machine in London. He was much struck by the improvements and advances which had been made since that time. In those days it used to be almost an axiom, with makers and consumers alike, that hydraulic machinery should be as simple as possible, even at the expense of using a little more water. Multiple power machines were in use, but they were somewhat crude in form as compared with the machines described in the paper. Cranes and hoists were made with three rams, of which the centre one was used alone, or the two outer ones only, or all three were used together. Wagon hoists were made with a direct acting balancing ram under a constant pressure. There were also machines made with a piston and ram so that the pressure might remain on the ram side, while there was pressure also on the piston side; and then by exhausting on the ram side full pressure could be obtained on the piston side. That was about all that was done in those days towards economising water.

Fire hydrants were incidentally mentioned by the author in connection with low pressure water. It might not be generally known that fire hydrants worked equally well from the accumulator pressure of 700 lb. per square inch, not put directly into the hose, but acting through a sort of injector, producing an induced current of low pressure water from a tank or pond. He (Mr. Adams) had sketched out this arrangement in 1874, and applied it on the Atlas Floating Coal Wharf for emptying the bilges, but it was afterwards arrived at independently and patented by Messrs. Greathead and Martindale. Their first application of it, he believed, was made at the London Docks

in 1879. The same thing had been recently applied at the Albert Dock Coal Hoists, and it worked very efficiently. The 700 lb. pressure water produced a sharp small current, and that sucked in water from the dock to give a pressure of about 150 lb. per square inch in the hose. The author had given some figures which ran into billions, and which were almost too large to be grasped. He thought that the same thing might be put in a very much simpler way by the statement that the figures 1,610,000,000 were equivalent to 2 gallons per minute of the accumulator pressure for 1 horse-power. But that was theoretical. Practically, with the simple hydraulic machinery, the 2 gallons per minute became $3\frac{1}{2}$ gallons per minute for 1 horse-power. That was from the actual measurement of a large number of cases and allowed for all losses. The lift shown at Fig. 1 had been spoken of as comparatively cheap, but "comparatively" was rather a wide term, for where the cylinders had to be bored the whole length the expense must be considerable.

With regard to testing, it was already the custom of some firms to have their passenger lifts tested periodically, and no doubt if, unfortunately, a big accident should occur, many more firms would at once do the same without legal compulsion. The fact that accidents did not occur was a testimony to the great care that was taken in designing lifts in general. The author had stated that there was greater safety with small cylinders than with large ones, as the former were less likely to burst; but, according to his (Mr. Adams') experience, both small and large were designed proportionately to the stress which would come upon them, and therefore he should expect the probability of bursting to be the same with each. In the case of the proposed balanced lift there was no doubt some advantage in being able to make up a large machine by duplicating or triplicating small stock parts, and that would appear to be one of the principal advantages. He could quite bear out the statement of the author that if the application of variable power was left to the attendant he would at once go to the full power to save trouble; therefore any arrangement for variable power ought to be automatic. The author appeared to have shown a method by which an automatic control could be obtained.

Mr. C. G. Major congratulated the author upon a paper which was most interesting and useful. The remarks made by Mr. Goodwin as to continuous lifts were, no doubt, borne out in practice. Lifts of that class were too slow, and were very noisy. Elderly people could not be got to use them, and of course the use of them by ladies was out of the question. For that reason

they were inapplicable to hotels. It was perfectly true, as the author had stated, that at the present time electric lifts were not equal to hydraulic lifts. The latter were far in advance. Possibly in the future that state of things might be altered. One advantage of the application of electrical power was that it could be adapted to the work to be done. The author had pointed out that an old-fashioned ram lift, with overhead balance weights, might be more dangerous than a suspension lift. That was true, for the strains of tension which were known to exist in the suspended lift existed to a much greater extent in the balanced lift, but they were not recognised. In the old-fashioned low pressure ram lift, the work was done chiefly by the balance weights. Out of a total upward strain of 2 tons on the ram head, one-fourth only was supplied by the water-pressure, all the rest being given by the overhead pull of the balance weight. Accidents had arisen from the ram heads being separated from the ram in consequence of the tremendous strain. Shortly after the accident happened at the Grand Hotel, Paris, some years ago, he had to inspect a lift in London where the ram head had been secured by eight bolts. Four bolts were entirely gone; two were without nuts; one had the nut half unscrewed; and the eighth bolt only was intact.

As to methods of balancing protrusion, his own experience was that the lever was best, because it produced less loss of power by friction. Although levers occupied very much more room than chains, it was possible to get the efficiency up as high as in some of the best suspended lifts. He had in his mind a case in which the efficiency, taking the up and down journey, was a little over 70 per cent. He believed that very few instances in practice exceeded that. He agreed with the author that, in suspended lifts, the ropes ought to be constantly examined; but he did not think they were. He had had some experience as to the wear and tear of ropes unequally loaded. The practice of his firm had been to put on four ropes. Two bore the average stress, one had about 250 lb. above the average stress, and the fourth was as much below the average. Between the minimum and the maximum there was therefore a difference of 500 lb. Consequently the rope which was most severely strained always broke first. There was no doubt that the fatigue to which the Chairman alluded was the ultimate cause of fracture, but that fatigue was concentrated where the wire was flattened. That could be avoided by reducing the pressure which caused the flattening. In connection with the safety gear Mr. Carey had mentioned a fifth or idle rope, which was provided in case all the four ropes broke together. He (Mr. Major) thought the author might be fairly challenged to

produce a case in which not only four but even two of the ropes broke simultaneously. He did not think that such a thing ever occurred. A number of cases showing that the ropes did not break simultaneously had come before his firm. In these cases the lift was one in which the safety gear acted immediately one rope broke, and put the cams into action. The stress due to the balance weight then came suddenly on the second rope. In those cases they had always found that the cage had been safely held and the balance weight dropped, both ropes being usually broken. The inference was that the ropes broke successively, the action of the grips occurring between the instants of fracture.

As to the special form of lift which the author had described, there was no doubt that it was an exceedingly ingenious contrivance; and having gone himself somewhat on the same lines, he must say that the author had evidently met various practical difficulties in an extremely clever manner. It was, however, open to question whether he had worked in a useful direction. It sounded well to have such a machine as that automatic, but automatic action could not be got without great complication. As to the possibility of stopping machines while ascending owing to the very small balance of pressure after the proper load had started, he asked whether that also occurred in descending. Mention had been made of the desirability of saving water which might be used for lowering loads. That must be done at the expense of still further complications, which, he thought, were not desirable. Referring for a moment to the question of varying powers, it was probable that only three powers would be necessary, and those might be controlled by hand.

Mr. W. Schönheyder said he quite agreed with the author that the compulsory examination of lifts was very desirable. He had seen a very simple arrangement in a few lifts which he thought ought to be universal: that was a hinged flap on each floor of the house and a flap on the floor of the lift, so that whether the lift went up or down it was quite impossible for the person inside to have his feet or head cut off. That device cost very little. As to the automatic device worked by a governor, the author admitted that it was not the best arrangement possible, as of course the lift might go slowly and not actuate the governor at all. Some of the other arrangements described by the author were evidently much safer than that. He should like the author to give them the actual saving in water by his appliances. Suppose a lift was made for a certain load, say a ton, and it was being used for only half a ton, how much water would be saved; or, *vice versâ*, suppose that one

ram lifted a certain weight, would two rams lift double the weight, or how much less on account of loss in friction; and so on.

Mr. A. Ker said that the lifts in Victoria Mansions to which reference had been made were old lifts. When they were put up the desire was to avoid very great expense, and the owner of the building proposed to put down a gas engine and an accumulator and pumps. The objection to the gas engine was the noise that it would make. An electro-motor had been substituted, and was available both night and day. It was not intended in any way to be specially economical. The cost of working a lift, however, compared very well with the Hydraulic Company's charges, but there had been no tests made, and he could not furnish any figures.

The Chairman asked Mr. Ker whether he could give any figures as to the efficiency of the motor and the pumps.

Mr. Ker said he did not remember exactly what the horse-power was, but the efficiency came out as nearly as possible at 50 per cent.

Mr. George Cochrane complimented the author upon the paper generally, and particularly upon the success of his water-saving apparatus. He asked whether the figures given were actual results, or whether they were calculated.

Mr. Carey said that they were actual figures taken from the indicator.

Mr. Cochrane said that the figures were very high, and would involve very careful measurement. They were much more than would be got from an ordinary lift man. The two periods mentioned were unequal, one being 275 days and the other 134 days. It would be more satisfactory to have equal periods. The work in one case might be less than in the other. However, the result was good whichever way it was taken, and engineers would probably hear more in future about the lifts in question. There was one point in connection with the power-setting valve which he should like to have explained. The author said that "for the third power the centre ram was opened to exhaust; the large ram then only has the two outside rams to oppose it." It seemed to him (Mr. Cochrane) that if the centre ram was opened to exhaust, the outside rams were opened to exhaust also, because the chamber in which that valve worked must either have pressure in it or be opened to exhaust, and he did not see how, if there was no pressure in the valve chamber, they could get pressure in the outside cylinders, unless there was some other way which was not shown. The valve itself would not keep tight with the pressure against it; and, even supposing that it did keep tight,

there would be compression in the cylinders. With no pressure at the back of the valve it must come off its face. That was a matter of detail which perhaps Mr. Carey could explain. He was very glad that an explanation had been given respecting the electric lifts in Victoria Mansions, but Mr. Ker had omitted to state that the hydraulic power had not been dispensed with. It had been used since the electric pumps had been fitted there. It was stated that no efficiency was attempted with the electric pumps. He did not see that any efficiency over the hydraulic power could be obtained in that arrangement. The comparison with the hydraulic lifts he was afraid had been made when the balances were out of use, which they had been lately very much, and therefore it was hardly reliable. If it had been made when they were in good order the results would have been different. In any case it did not seem to him possible to supply electricity to work lifts in that way at 5*d.* per Board of Trade unit against the Hydraulic Company's charges. The efficiency of a good lift was certainly more than 50 per cent. If they were content with 50 per cent. in electric pumps, he did think they could compare them with hydraulic lifts worked from the mains at all. The author had referred to the safety of the automatic economising lift, and had stated that there was very little danger should any one be caught between the floor of the cage and any part of the enclosure. If the lift was easily stopped by hand as stated, there could not be much speed in it. There must be an excess of power to obtain speed.

Mr. L. MILNE said the author had remarked that electric lifts would not come largely into use in the future. He was interested in electric lifts, and not prepared to endorse that statement. It was well not to prophesy unless you know; but he should like to examine the reasons on which the author had based his opinion. The first point was that electric motors necessarily ran at a high speed, and consequently worm-gearing would be required. No doubt that was in a large measure true, but he did not think it was for a moment true that worm gearing necessitated a jerky action of the lift. In the experience he had had, both in connection with electric cranes and with passenger lifts, worm gearing had not produced a jerky action. On the contrary, the electric cranes which his firm had recently erected with worm gearing worked with an excessively smooth movement. Moreover he could give as examples of lifts with worm gearing, one at a house in Bond Street, and another at the Crystal Palace running up to one of the galleries, which had been working for a considerable time, and neither were at all jerky in their action. The author's second point was that electric lifts could not be safe, but at the same time the author

was of opinion that suspension lifts were as safe or safer than ram lifts. No doubt there were some present who could speak with very much greater experience on that point than he (Mr. Milne) could; but, assuming that the author's view was correct, it was not conceivable that an electric lift should not be the safest of all kinds of suspension lifts, for the reason that the power was more absolutely under control than could possibly be the case with steam or hydraulic lifts. The author did not allude to the important question of economy in connection with electric lifts. He had put before the meeting most ingenious arrangements for economising water power, but it appeared to him (the speaker) that the employment of electricity was a far more simple road to economy, because, from the nature of things, the power employed was only that at the moment required.

As to the lifts referred to in Victoria Mansions, he took it that they were not put down with the idea of economy, and it would not be fair to cite them as an example of the economy of electric power. He thought the previous speaker had misunderstood the remark that the efficiency there was 50 per cent. It was hardly possible that this referred to the electric motor, the efficiency of which could hardly be less than 80 per cent. He inquired whether the 50 per cent. did not refer to the efficiency of the whole apparatus, including pumps, lift, &c.

Mr. Ker mentioned that the ball bearings to which the Chairman had referred had given no trouble so far.

Mr. H. C. Walker, referring to Mr. Major's challenge for any one to cite an instance in which the four ropes had broken at once, said that until last year he (Mr. Walker) had never met with such a case, and had never met with anybody who had; but last year in Australia he saw a lift in which all the ropes had broken at one and the same time, and they had broken within 3 inches of each other. The lift was running at a very great speed, and the boy who was in the cage, being very careless in stopping, jumped the ropes right off the top wheel on to the spindle where the key was, and the ropes broke. They had been condemned before, but the proprietors would not take them off. The accident was entirely their own fault. Fortunately, having good safety gear, nobody was really hurt. He would endorse the remarks of the author as to an idle rope. With regard to a question which had been raised by the Chairman, his own experience was that an idle or light running rope lasted very considerably longer than one which bore a strain. He had known a case in which the idle rope had lasted out two sets of the other ropes. It had been suggested by one speaker

that the saving through using Carey's water-saving machine was not worth effecting; but his (Mr. Walker's) opinion was quite the contrary, and he was quite sure that the Hydraulic Power Company also, who so admirably looked after their consumers, would hail the economy with pleasure, because it would tend to bring them more customers, and thus in the end more profit.

As to electric lifts, he agreed more with the last speaker than with the author as to the prospect of their coming into general use, although they were not by any means perfect at present. He did not think that any electric lift which was constructed with worm gearing would ever work as smoothly or as efficiently as a hydraulic lift. But there were different forms of electric lifts, some of which would in a few years be great competitors with hydraulic lifts. At the same time electric lifts, to be successful, must be on a totally different principle from those which were already in vogue. About two years ago he went in two electric lifts in America, and he must say that they ran very well, but there was that jerky sensation which would always accompany the worm and wheel. The Chairman had remarked that it would be quite possible to cut a worm and wheel so that there should not be any very great motion. It would be possible, but when the worm had been at work for some time and began to wear, there would be an unequal motion.

Mr. C. F. Archer said he should like to know how the water-saving appliance was adjusted to meet the gradually increasing load in a direct-acting lift where protrusion took place. In a very high lift the amount of protrusion of the ram would be as great as the actual load which was carried, and therefore as the lift approached the top the load would be double what it was at starting, and the speed all the time gradually decreasing.

Mr. J. W. Wilson, jun., said that when the Brighton Railway Company applied for the Act for their Crystal Palace line some forty years ago, they took powers to construct their low-level station near the present position of the south water tower, and the chief reason why that was not carried out was that the company saw no way in those days of raising a large number of people by means of lifts such as would have been necessary. They therefore had to place their station further off, and provide access to the Palace building by sloping corridors. Such lifts as Sir Douglas Fox had introduced on the Mersey Tunnel Railway were capable of carrying a large number of passengers, and that example was being frequently

followed. The author had devoted a portion of his paper to the question of the safety of lifts, and the meeting had just heard some remarks as to the number of ropes which should be used for that purpose. The author put the point in the following words:—"The multiplication of ropes, and the excellent safety appliances now in use, leave little to be desired in preventing accidents by the failure of ropes; but there is another inherent source of danger connected with suspended lifts, although happily a remote one, that is the failure of the overhead sheaves or spindles. Beyond making these of extra strength, it is not usual to take any special precaution." Surely there were safety clutches in use which were entirely independent of the lifting apparatus of a cage. He (Mr. Wilson) had frequently travelled to the top of an ordinary blast furnace in a cage which was suspended upon a single rope and provided with such a safety clutch. If the lift in question broke away from any accident whatever, it at once brought into action the inertia of a weighted lever, by which the gripping cam was brought into action and the cage fixed *in situ.* The action was perfectly safe and satisfactory, and though it might be said that people were shy of such an arrangement, and did not like to feel that their lives were hanging upon a simple apparatus of that kind, it was not necessary for travellers in a lift to see the safety apparatus which was to prevent them from being hurled to the bottom of the well. He did not necessarily advocate the use of only a single rope, but it appeared to him that it would be a simple thing to superadd to existing safety appliances such a simple arrangement as the one he had mentioned, so that there might be no possibility of danger to the passengers from the breaking of the overhead gearing or any other cause. It was obvious that anything that could be done to prevent accidents should be adopted.

Mr. Carey, in replying, said that the Chairman had remarked that the continuous lift was slow, and that people would rather wait until a cage descended, and then go up quickly. There was no doubt the Chairman was right. When people were in a train or lift, or any other moving vehicle, they liked to drive along at full speed, and they were going more and more in that direction. As to the safety gear for continuous lifts, there were several ways in which, if the cages became detached from the chains, they were prevented from descending, and the lift would be brought immediately to a standstill. The cages would not descend one upon the other; the mere fact of a cage becoming detached from the chain stopped the lift. He had had no experience with regard to ball bearings, but he had no doubt that they would work well if

they would wear. Of course they would considerably reduce the friction. As to the examination of overhead sheaves, to see that they had no flaw, he did not think that any test could be really applied. The word "test" was, perhaps, improperly used in the paper. The Chairman referred to the balancing of the water-saving lift, and the balancing of the ordinary lift with which it was compared. Both lifts were balanced as nearly as they could be, so that the cage would only just descend at a fair speed when empty. Therefore, there could be no more balance applied. As far as that point was concerned, both lifts were under the same conditions. The speed of the lift, a matter which had been referred to by several speakers, was one of the points of difference between his patent water-saving lift and the ordinary lift. There must be a certain speed attained before the governor ball would fly out, but of course it must be regulated for a moderately slow speed, in order to obtain economy. If it was arranged so that the governor ball would only fly out when a high speed was attained, there would be a loss of economy. But, on the other hand, the economy even then was very well worth the extra outlay for the one extra valve and the two extra rams. Those were not very large, as they were only equal in area to the one which was necessary in the ordinary machine, and therefore the extra cost was not very great. A question had been asked as to the speed at which the lift was running when it was stopped by hand, but he could not give information upon that point. He believed that it would be from 100 to 150 feet per minute. When the lift was running at a higher speed than that, the extra power would be too much to allow it to be stopped by hand. On the other hand, however, the power would not be so much that any one who was forced between the cage and the enclosure would be seriously injured. The lift would stop rather than seriously crush such an obstacle.

Mr. Adams had referred to the direct-acting lift with a bored cylinder, and said he did not understand what was meant in the paper by the term "comparatively cheap." It meant that the lift was comparatively cheap with regard to the hydraulic balance lift. It was equally safe, but there was no separate machine. The bored cylinder, with the balance weight working down the well, gave everything as far as safety was concerned, that was attained by the direct-acting balance hydraulic lift, but at a much cheaper cost, and much less room was occupied With regard to the smaller cylinder not being safer than the large cylinder, he thought Mr. Adams would allow that the larger cylinder was at a disadvantage as compared with the

smaller one. The same amount of metal in small cylinders gave a much higher efficiency than it would in a large cylinder, and, besides that, the bursting of one cylinder through a flaw would not cause the lift to descend. The only dangerous accident which could occur to a suspended lift which had a good safety apparatus, was, he believed, the bursting of a cylinder, because the weight of the piston and cross-heads, &c., prevented the safety apparatus coming into action, and therefore the cage would descend, merely pulling the weight of the piston rod and piston to the top as the cage came down. The safety apparatus would be kept out of action by the pull of the ropes.

Another question related to the simultaneous breaking of all four ropes. Mr. Walker said that such a breaking was not impossible; but, assuming that it was impossible that all four ropes should break simultaneously, yet, supposing that the spindle on which the overhead sheaves revolved was to break, the effect would be the same. The whole of the ropes would be loosened simultaneously, and the safety apparatus would have no means of being put into action and the cage would descend. Mr. Major had argued for one valve only, and for not going from one power to another automatically, but using a movement of the rope. He did not mention in what way he would get from one power to another, but he must have more than one power, and he must go from one power to another in some way. Mr. Major would have one valve only; and the machines certainly would be cheaper than the machine shown, in which there were two valves and three rams. He must have his three rams and one valve, and he was depending upon the lift man working either one, two or three powers. He (Mr. Carey) would leave it to the judgment of the meeting whether that plan was likely to be as economical as the automatic arrangement. The stopping of the lift in its descent might be arranged either way. In some cases, where more economy was required, the lift might be made to return the water, or it might be made to raise the load as shown in Fig. 4, or to raise the weight and store up the energy. In that case, the descent was actually the same as the ascent. There was no surplus power, and therefore it would not seriously injure a person if he got caught between the cage and the enclosure. As to moving the lift from one power to the other by hand, it was obvious that the attendant would go at once to the greater power, and therefore the machine would not be economical. Mr. Schönheyder had asked what would be the amount of water in the case of a lift intended for raising a ton, if only half a ton was in the cage. The answer was, that it would be something more than half the

quantity of water, because the friction of the ton would not be double the amount of friction of the half ton. Mr. Ker had made a remark as to the electrically driven pumps. Surely it must be more economical to use either water direct or electricity direct, and drive the lift by electricity.

Mr. Cochrane had mentioned the unequal time in which the lift would descend in working on that principle. He was quite correct. When the lift was working nearly to its maximum power, it travelled more slowly. Supposing a crane was capable of raising 5 cwt. and there was only 1 cwt. upon it, it would go the faster. When there was 4 cwt. it would go slower, but it could be arranged to go any speed. Mr. Milne had spoken of worm gearing which ran perfectly smoothly in connection with electric lifts. He (the author) could not quite agree with the statement that worm gearing would run smoothly. It appeared to him that a worm would almost always give waves of motion. Therefore it seemed to him that the electric lift must have a screw, and not a worm wheel. There was a great loss by friction in the worm and wheel, and there was more in the screw. It was a mystery to him why the electric lift should be more under control than the hydraulic. His own experience was that the hydraulic lift was infinitely more under control than the electric lift.

Mr. Archer had asked how he (Mr. Carey), would get over the difficulty with the balanced lift. Where the protrusion was not balanced, the lift would start with a much heavier load than it would carry to the top of its journey. That was, of course, true. But if the protrusion was not balanced there must be a certain amount of spare power when starting. It was simply necessary to regulate the governor so that the power-setting valve was not stopped until a certain speed was obtained ; then there would be power enough to go to the top. The difficulty was got over in that way. Mr. Wilson had referred to a lift in which the cage was suspended by one rope, and he had implied that that lift was as safe as a lift suspended on a multiplicity of ropes. He (Mr. Carey) could not agree with that view. If the ropes were equally strong, two must be safer than one. Where there was a safety apparatus which acted by a weight on a lever, why should the inertia of the weight put the safety apparatus into action at all? Why should not the whole thing come down at the same speed?

Mr. Wilson: But it does act in that way.

Mr. Carey said he presumed the solution was that there was a certain amount of friction of the air, and that the cage, being large, must displace a certain amount of air, and there

was a certain amount of friction, and therefore it did not fall at the rate that a smaller weight did. It seemed to him to be a very poor thing to depend upon. He knew a case in which there was a safety apparatus which was to throw out catches in a kind of ladder on each side, but when the rope broke, the cage came down rapidly. The fact was that the movement of the weight never had time to place the bolts far enough out to catch on the rungs of the ladder. Therefore it simply came down. He had replied to all the questions to the best of his ability, and he must thank the meeting for the very gratifying reception they had given to his paper.

Fig. 1.

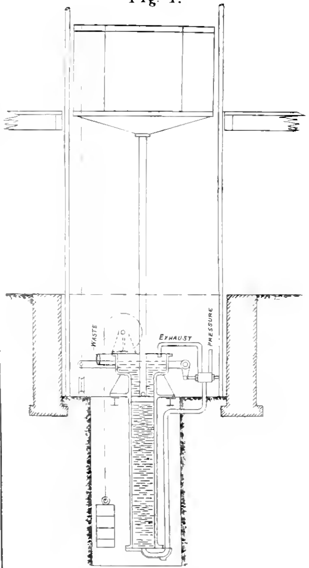


Fig 2.

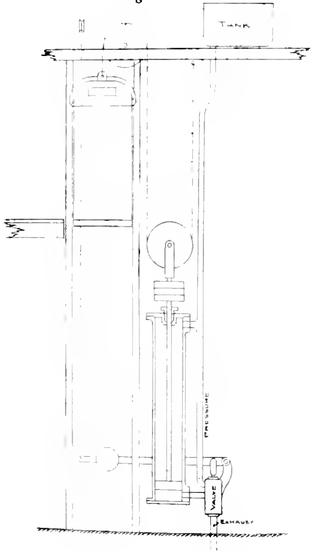


Fig. 3.

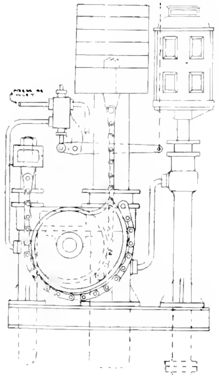


Fig. 4

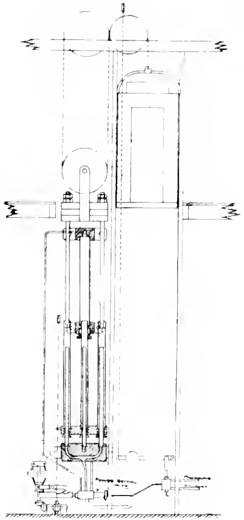


Fig. 5.

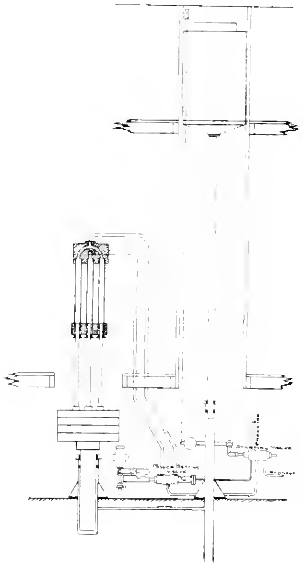
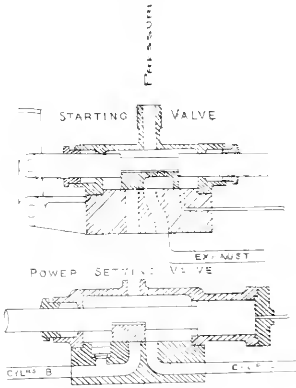


Fig 6.



VACATION VISITS.

THREE vacation visits were made during the summer and autumn of 1893. The first, on May 31, was to the Water-works, Gas-works, and Harbour Improvement Works at Ramsgate. The second, on July 5, was to the New Lock and Weir Works, and the Water Works at Richmond, Surrey. The third, on October 11, was to the Tottenham and Forest Gate Railway, in course of construction. The following are general descriptions of the several works.

RAMSGATE WORKS.

On their arrival at Ramsgate the visitors were received by the Mayor and members and officials of the Corporation, and were entertained at luncheon at the Water Tower. This tower was erected in 1878, to afford a constant supply of water to the town. It is built entirely of brickwork, 50 feet by 80 feet on plan, and 60 feet high, being surmounted by one of the largest elevated cast-iron tanks in the country, which is 10 feet deep, and holds 250,000 gallons. The weight of the tank is thrown entirely on the cross walls. The whole of the brickwork is composed of common stocks, except the facing of the outside walls, which is of Mid-Kent wire-cut red bricks. The pumping main is 15 inches diameter and the distributing main 18 inches. The water is raised from Whitehall, a distance of about two miles, and pumped into the bottom of the tank, the overflow being in direct communication with the low level reservoir, holding 750,000 gallons. This arrangement obviates the necessity of making any alteration in the valves during pumping hours. The difference in level between the bottom of the well and the top of the tower is 220 feet.

From thence the Members were conducted to the Gas-works, which were purchased by the town in 1878. Immediately after the transfer it was found necessary to entirely

reconstruct the works. The present capacity is about 200 million cubic feet per annum. The retort house consists of fourteen beds of six retorts each, and five beds of eight retorts each. Gaseous firing is used throughout, and West's manual machinery is used for charging and drawing. The condensing, scrubbing and washing apparatus need no special notice in this summary, but it may be mentioned that the purification is accomplished by what is known as the oxygen process. The method of producing the oxygen is as follows:—Air is pumped under a pressure of about 15 lb. to the square inch into cast-iron retorts filled with barium monoxide heated to a temperature of 1400° Fahr. At the end of about three minutes after the barium has become per-oxidised, the operation is automatically reversed, and the retorts being placed under a vacuum, the barium yields up its extra oxygen, and returns to the state of barium monoxide ready for another operation. The oxygen thus produced is stored in a holder, and then admitted into the purifiers, causing them to run a much longer time without change, at the same time having a beneficial effect on the illuminating power, and rendering the spent lime inodorous. The gasholders, of which there are two, have a capacity of 650,000 cubic feet. These in the course of another year will be supplemented by another holder containing about one million cubic feet.

From the Gas-works the visitors proceeded to the Front and Harbour Improvement Works. For the last fifty years the necessity for better communication between the cliffs and the sands has been felt, and various schemes to attain that object have been brought forward at different times, but none, until the present one (which was also the first to get the consent of the burgesses), proposed to interfere with the Inner Basin. The water along the north or Military Wall of the Inner Basin was so shallow as to be of little use in berthing vessels, &c. The work being carried out at the time of the visit was commenced in January 1892, and consists of a new basin wall to cut off the shallow part, a rising road from York Street to the West Cliff on the site of the old Military Road, a rising road to the East Cliff, and the pulling down of the Customs House and harbour master's house (which will be rebuilt in another position) and the warehouses in the Pier Yard, so as to widen

the approach to the London, Chatham and Dover Railway and sands from the present 15 feet to 60 feet. The sea wall is built of concrete and faced with Portland stone, and coped with granite 18 inches deep. The wall is 30 feet high, 5 feet 6 inches thick at the bottom and 4 feet at the top, with 4-foot counterforts at intervals of 30 feet. The rising road to the West Cliff is carried on semicircular arches 30-foot centres. The party walls are of concrete, the lower ones being 2 feet 6 inches thick at the springing, and the more lofty ones 3 feet. The arches are built of picked stocks, the thickness being 18 inches. The front arches are built in red Pluckley bricks, with a moulded cornice and terra-cotta balustrade. The road will have an inclination of 1 in 25. The carriage-way will be macadamised, and 30 feet wide. The footway will be of asphalt, 15 feet wide. The approach to the East Cliff, to make room for which the Albion Hotel is to be removed, will follow the natural conformation of the ground, and will have an incline of 1 in 14. The approach to the sands will be paved with wood in place of the present cobbles. The Customs House will be rebuilt on the opposite side of the road, and the harbour master's house will be rebuilt on the West Cliff. Besides these improvements, the small cottages on the north side of lower Harbour Street will be removed, and the site laid out in ornamental gardens. The works were being carried out by Messrs. W. and T. Denne, contractors, from the designs and under the superintendence of Mr. W. A. McIntosh Valon, J.P., Borough Engineer, and President of the Society for the present year.

Richmond Works.

At Richmond the visitors were received by the Mayor and members of the Corporation, and were conducted over the Lock and Weir works by Mr. P. le Neve Foster, Resident Engineer. The object of these works, which are being carried out by the Thames Conservancy, under the direction of their engineer, Mr. C. J. More, M.Inst. C.E., is to increase the depth of water in the River Thames between Richmond and Teddington Lock, at, and for some time before and after low water. The works consist of a foot bridge 348 feet in length, having five arches,

crossing the river at right angles about 400 yards below the London and South Western Railway bridge; a lock on the Surrey side; and a boat slide with three lines of rollers on the Middlesex shore. The three central arches have 66 feet span, and the end arches (one of which is over the lock and the other over the boat rollers) 50 feet each. The girders, which are arranged to carry a double gangway, are of steel. The three central arches are being fitted with removable sluices, the invention of Mr. F. G. M. Stoney, M. Inst. C.E., capable of holding up the water to 5 feet 2 inches below THW (about half tide ordinary springs). These sluices, the largest ever constructed, are 68 feet long, 12 feet deep, and weigh about 32 tons each. They are suspended at each end by steel wire ropes, which pass over the pulleys of the lifting gear; counter-balance weights are attached to the ends of these ropes. These weights are four in number, of 8 tons each, suspended in 3 feet square wells built into the masonry of the piers. The wells, which are made of steel plates, serve also to support the vertical guides, which are planed surfaces of cast iron, between which and the cast-iron ends of the sluices are interposed the free rollers, arranged in such a manner as to take the pressure of the water, and thus can be easily moved. In addition to the counter-balance weights, they are also fitted with special balance weights to compensate for the varying weight of the sluice when in or out of water. Thus a perfect balance can at all times be maintained, and consequently the sluices can readily be moved by hand power. When the sluices are lifted they can, by an ingenious arrangement, be turned over flat between the two gangways, and are hidden from view by the girders and parapet of the bridge, so as to allow a clear headway for vessels passing underneath the bridge of 21 feet above THW mark, or about 4 inches more than at Richmond railway bridge. During floods the sluices need not be lowered at all; but at other times they will be shut down at about half ebb and lifted again at half flood, and the arches will then be open for navigation, the lock being used only when the sluices are down. The counter-balancing of each sluice is so perfectly adjusted that the buoyancy of a timber float fixed on the up-stream side is sufficient to float it and cause it to lift with the rising tide; this will also regulate automatically the flow of the stream underneath at low water,

and maintain a nearly fixed level of water above the bridge. The lock is to be 250 feet long (72 feet 7 inches longer than that of Teddington), and the gates will have a clear opening of 26 feet (13 inches wider); but, in order to accommodate a tug and full complement of barges, it is widened out on the shore side to 37 feet for about two-thirds of its length. The cill level of the entrance is 16 feet below THW, which will allow a depth of water of about 6 feet at the ordinary summer low-water level. The rollers of the boat slide will be laid on a concrete floor, with an incline of 1 in 8. The abutments and piers of the bridge, as well as the walls of the lock, are built of Portland cement concrete, faced with Staffordshire blue bricks and Cornish granite. The sluices are made of steel, with the exception of the end bearings and the trunnions upon which they turn from the vertical to the horizontal position when raised out of sight. The estimated cost of the works is 61,000*l.* The contractors for the sluices and superstructure of the bridge are Messrs. Ransomes and Rapier. The concrete foundation of the pier was put in on March 25, 1892, and it is anticipated that the work will be completed by the end of the present year.

The Members then proceeded to inspect the water-works, over which they were conducted by Mr. W. G. Peirce, the engineer. These works were commenced in 1876 by the the laying of about 22 miles of cast-iron water mains, varying from 14 inches to 3 inches diameter, with hydrants; the conversion of the old brewery at the bottom of Water Lane into a pumping station; the sinking of two wells, the dummy or pumping well, 8 feet 6 inches diameter by 140 feet in depth, and the artesian well, 7 feet diameter, reduced to 3 feet at a depth of 254 feet (on surface of chalk)—from this level the boring commences, and has been carried down to a depth of 1446 feet, varying from 2 feet to 7 inches diameter, terminating in the red sandstone. The expectation of a sufficient supply of water not having been realised from this source, a certain proportion of water is drawn from a shallow well situated in the Petersham Meadows, 1100 yards distant from the Water Lane works, and connected by a 9-inch syphon pipe with the dummy or pumping well. Owing to the steady increase of the population and the greater consumption of water for all sanitary purposes, the Water Supply

Committee took into consideration the necessity for increasing the supply of water, and in the year 1887 requested Mr. Peirce to prepare plans and estimates for sinking a new well to the chalk, and driving adits in various directions to intercept fissures, and by this means improve the supply. The well has been sunk 9 feet 6 inches diameter, in brickwork, through the London clay, reduced to 8 feet and 7 feet diameter, with cast-iron cylinders, through the Thanet sands, and 6 feet 6 inches diameter into the chalk, to the depth of 320 feet from the surface of the ground. At this depth adits have been driven 6 feet by 4 feet 6 inches in several directions, amounting at this date to nearly 4000 feet; the greatest length in one direction, 2378 feet, connecting the new well with the old well at Water Lane. Soon after starting adit driving, the Corporation purchased the contractors' plant, and have since carried out this part of the work by their workmen. Owing to the limited supply obtained from the wells, a duplicate system of mains and pumping plant has been provided for, giving a constant supply of water from the river for road watering and sewer flushing.

At the time of the visit there were five pumping engines—one 25 horse-power Robey, two 50 horse-power beam engines (compound), one 25 horse-power compound direct-acting, &c., and one 10 horse-power special pump—at work, with four steam boilers (viz. three 50 horse-power Field patent vertical, and one 25 horse-power semi-fixed), raising water from the several sources (the greatest depth being 320 feet from the surface of the ground, supplemented when required with a supply from the Southwark and Vauxhall Company) into a service reservoir in Richmond Park, 142 feet above the old pumping station, having a total capacity for storing 750,000 gallons. The reservoir, although built upon the highest ground in the neighbourhood, will not supply the top cisterns of about forty houses on the terrace by gravitation. For that a special balanced valve on the 14-inch main leading to the reservoir has to be closed daily, while the pumping is continued to fill these high-service cisterns. The total consumption of water for the year ending 25th March, 1893, was 207,769,428 gallons, averaging 569,305 gallons per day, and, say for 23,000 consumers, 24·7 gallons per head per day. A contract has been entered into with Messrs. C. Timmins and Sons, of Runcorn, to fix 65 feet of new

4-feet diameter cast-iron cylinders inside the original 5-feet diameter cylinders, previous to enlarging the bore-hole from 2 feet diameter to 3 feet 6 inches diameter to the adit. It is intended to put down new pumping plant for the purpose of pumping all the water obtained from the adits at the old works, thereby avoiding having two pumping stations, and obtaining economy in the cost of fuel and labour.

Tottenham and Forest Gate Railway.

For the inspection of the works of the above railway the Members proceeded to South Tottenham, where they were received by Mr. Arthur Nunn, the resident engineer, and Mr. Henry Turner, the contractors' agent, by whom they were conducted over the line, which forms an important link in the suburban railway system of the Metropolis, and an equally important connection between the port of London and the Midlands. The railway was originally promoted by Mr. Courtenay Warner, of Walthamstow, and was afterwards taken up by the Midland Railway Company and by the London, Tilbury and Southend Railway Company. The line is 6 miles 4 chains in length, and the object of its construction is to make a connection between the two railway lines just referred to and the Tilbury Docks, to provide additional railway accommodation for the district to the east of the valley of the River Lea, and to provide coal depots on an extensive scale along the line. The line starts, by a junction with the Tottenham and Hampstead Railway, at the South Tottenham Station, and passes between the great reservoirs of the East London Water Company into Walthamstow. It passes then successively through Leyton, Wanstead, West Ham and East Ham, finally making a junction with the Tilbury line at Forest Gate, near Romford Road. At each of the above points the line passes through a populous district. Intersecting, as this railway does, a considerable number of roads and streets, it is not surprising that, in its comparatively short length of a little over 6 miles, there are no fewer than 72 steel bridges, absorbing more than 4000 tons of Siemens-Martin steel. Of these bridges, 15 are over- and 57 under-bridges of various spans and types, no two being alike, while most of them are skew bridges, in one of which the rear

end of the girder on one side is about on a line with the forward end of the girder on the other side. The line, for about half its length, is carried on embankment and in cutting, but 3 miles of it consists of a viaduct of brickwork arches, each of 30 feet span. The gradients throughout are easy, and the curves good. Concrete is largely used in the construction of the various works, especially in the retaining walls, which absorb a very considerable quantity of that material. There will be five passenger stations, and four goods and coal depots along the line. The stations will be at Black Horse Road and Shrubland Road, Walthamstow, respectively; Leyton High Road; Leytonstone High Road; and Wood Grange Road, Forest Gate. Three of these stations will be built on arches, the other two being in cutting, and in each case the platform will be 500 feet in length. The quantity of materials employed, and the earth shifted, in the construction of this line are very considerable. There will be 81,894 cubic yards of brickwork, involving the use of upwards of thirty million bricks. Then there will be about 4000 tons of steel and ironwork, exclusive of rails and permanent way, while there are over 300,000 cubic yards of excavation. The contract amount is 264,422*l*., exclusive of station buildings. Nearly 1000 hands are employed on the works, together with four locomotives and a number of steam cranes. The engineer of the railway is Mr. Arthur C. Pain, M. Inst. C.E., and the contractors are Messrs. Lucas and Aird. The line was commenced in August, 1891, and rapid progress had been made at the date of the visit.

October 2nd, 1893.

WILLIAM A. McINTOSH VALON, President, in the Chair.

GAS SUBSTITUTES.

By Professor Vivian B. Lewes.

During the 100 years which have elapsed since Murdoch first discovered coal gas, there have not been wanting attempts to form gaseous mixtures by other means than the retorting of coal, which would rival that great gaseous illuminant for lighting purposes. No sooner had coal gas been accepted as an accomplished success, than various schemes were started for making other gases capable of distribution through mains and pipes to compete with it, and the gases which have been proposed to take its place may be roughly classed as follows:—

(1) Oil gas, produced by the decomposition of liquid hydrocarbons by means of heat.

(2) Air gas, consisting either of air carburetted with the vapours of highly volatile hydrocarbons, or else of mixtures of oil gas and air.

(3) Carburetted water gas, in which a mixture of carbon monoxide and hydrogen, produced by the decomposition of steam by incandescent carbonaceous fuel, was given illuminating properties either by saturating it with the vapour of liquid and highly volatile naphthas, or else by admixture of oil gas, either made simultaneously with it in superheating chambers, through which it was passing, or else made separately and afterwards mixed with it.

These three classifications practically cover the whole of the processes which have been proposed, although there have been many varieties of hydrocarbon used to give the illuminating power, and also many variations in the form of apparatus employed.

The fact that oils could be decomposed by heat into gases having a high illuminating value was known even before the introduction of coal gas, and as soon as the use of gas for illuminating purposes became an established success, many

attempts were made to utilise liquid hydrocarbons in place of coal for its production. The price of oil, however, in this country has always been sufficiently high to prevent oil gas entering into competition with coal gas, and its practical manufacture up to the present time has been restricted to the preparation of gas for compression, as in the Pintsch and similar processes, or for installations in country mansions and public institutions where the consumption was insufficient to render the manufacture of coal gas remunerative. It would be useless to enter into a consideration of the various types of apparatus which have been proposed from time to time, and most of which have been designed without the least knowledge of the changes undergone by the hydrocarbons on exposure to high temperatures, and it will be sufficient to give merely a brief outline of two typical processes and the results to be obtained from them.

The Patterson process for retorting oils only differs from the Pintsch and half-a-dozen other processes in the shape of the retort. All such methods of decomposition result in the formation of gas and also liquid and solid residuals. The Patterson plant consists of a horizontal retort of a cylindrical form built into a furnace, containing an oven or flue space in which the retort is placed. The oil to be converted into gas is led from the oil tank into the retort by two straight horizontal pipes extending from the front nearly to the back of the retort. The inner or back ends of the pipes are open. The supply of oil is partly converted into vapour in passing along these pipes, and, issuing from their inner ends, is further decomposed by the heat in passing from the back end to the front of the retort where the outlet is situated. The main supply of oil from the oil tank is regulated by a stop-cock, while the supply to each retort pipe is separately regulated by a small tap. The gas formed in the retort passes off to an ordinary atmospheric condenser and then to the gas-holder. The arrangements are such as to allow of the action being easily and satisfactorily regulated and controlled.

In making an oil gas in any such apparatus, the essential points which will govern the selection of material to be employed are—first, the cost of crude material, and secondly, ease of working; and in a long series of investigations, which have been made by the author to ascertain which would be the best hydrocarbon to employ, and the best temperature to work at, it was found that the temperature which gave the best results was 900° C., and that the oils best adapted for use were the Russian Solar Distillate—obtained by subjecting the residuum of the Russian Baku oils, after the lighter kerosenes have been

driven off, to further distillation—and nearly as good as this were the blue and green shale oils. Working with these oils at a temperature of 900° C., the best results obtainable per gallon would be 98 cubic feet of 50-candle gas, which would be equal to 980 candles per gallon of oil, and in each case there would be about 20 per cent. in volume of original oil condensed as residuals, these residuals containing a certain amount of benzine as well as paraffins and olefines of low boiling points, but which are of very little use for recracking.

Dr. Dvorkovitch is strongly of opinion that the future of carburetting by oil is dependent upon the oil being cracked in such a way as to yield large percentages of residuals rich in benzine, but when it is considered that such residuals are of extremely fluctuating value, and that any increase in their production would quickly reduce their value to a point at which they are practically unremunerative, it will be seen that this is a fallacy, and the gas manager would only be too glad to wash his hands of such an uncertain item in his yearly balance sheet, rather than to increase his responsibility by making such residuals in large quantities. Unless oil can be obtained at a price at which it will pay to convert it all into illuminating gas, it will never be able to compete with coal at its present price.

From time to time attempts have been made to make oil gas in such a way that there shall be no liquid residues, and that the whole of the oil shall be converted into gas or left as a solid residue in the retorts. The first process of this kind was the one introduced by Hilary in 1846, who placed tube condensers above his oil retorts, so that all the liquid condensed ran back to the retort and became further carbonised, his ultimate products being nothing but coke and gas. This idea has been revived and improved upon during the past year by Mr. W. Young, who has erected a very ingenious plant at Peebles and elsewhere for the gasification of oil. Young's process for the manufacture of oil gas from the Scotch shale oils is entirely dependent upon the principle of washing the oil gas retorted at a moderate temperature by means of the oil which is afterwards to undergo decomposition, a process which frees it from all condensable vapours and allows only permanent gases to escape to the purifiers. There is no doubt but that in doing this very considerable quantities of the olefines and other fixed gases are also absorbed, but, as these are again driven out by the action of heat during the retorting, no loss takes place.

The installation at Peebles consists of two cast-iron retorts about 10 feet in length, set so as to incline downwards to the far end. They are fitted with doors and ascension pipes in

the usual way, but in each door there is a small pet-cock, by opening which the colour of the gas can be seen. This should be of the palest lemon, as it is found that if any darker colour or an approach to brown is produced, decompositions of tar and other troubles commence. The oil to be cracked is admitted through small cocks about 2 feet up the ascension pipe, and falls down through the ascending gas on to steel plates, which extend 3 feet into the retort, so as to prevent, as far as possible, the direct impact of the oil upon the bottom of the iron retort. The retorts are heated to from about 800° to 900° C.

As the gas leaves the retorts it passes up the ascension pipes to the hydraulic main, and through a coil of horizontal condensing pipes to the scrubber, which is of the well-known Young pattern, and is made in four compartments. The oil cistern is situated on the top of the scrubber, and the supply pipe therefrom is so arranged that the oil can be made to flow into any one or all of the sections. Having passed through the scrubber, the oil flows back along the bottom of the horizontal condensers, in an opposite direction to that in which the gas is passing, and into the hydraulic main. From the main it passes through a seal into a small cistern containing a float, which is in connection with an indicator close by the oil feed taps in the front of the working bench, so that if the oil is either flowing faster than it is being decomposed, or is not flowing sufficiently fast, the supply of oil from the cistern can be regulated so as to keep the balance constant. The oil used is what is technically known as "blue oil," and has a specific gravity on an average of about ·850. It is claimed that each retort will make 500 cubic feet of gas per hour, and 5½ cwt. of a very dense graphitic coke is deposited in the retort for each ton of oil decomposed. This coke collects almost entirely near the back of the retort, and, shrinking from it, can readily be removed. The coke forms with a practically horizontal surface, which suggests that it has flowed to the back of the retort in the condition of pitch and has been carbonised there, or else carbon deposited in the ascension tubes and front of the retort has been washed there by the oil.

The gas obtained by the Young process, when tested by itself in burners most suited for its combustion, gives in the photometer an illuminating value averaging from 50 to 60-candle power, but it is claimed that the enriching property of the gas is considerably above this. The reason for this is that the duty obtained from any burner is entirely dependent upon the regulation of the size of the flame, so that the gases as they burn, shall get a proper proportion of oxygen within a

given distance from the nozzle of the burner, and secondly the temperature of the flame itself. This means that every variety of gas will give different illuminating values when burnt in varying burners, the burner adapted for poor or medium gas being utterly unfitted for rich gas, a point which is far too often overlooked, not only in testing the illuminating value of gases, but also in their practical consumption. A 16-candle power coal gas requires a very large burner to develope its maximum illuminating power as a flat flame, but as the richness of the gas in heavy hydrocarbons increases, the size of the burner has also to be rapidly decreased, in order to allow sufficient air to get to the flame, and the smaller the flame the greater will be the cooling influence of the burner and the nitrogen of the air upon it, with the result that a burner has to be selected for each quality of gas of such size that it will just not smoke.

Take, for instance, an oil gas capable of emitting a light equal to 50 candles per 5 cubic feet, it would be found that in the No. 2 Bray burner it would give a heavy smoke flame, and this trouble would be increased with increase in the size of the burner; but if a No. 0 Bray were employed, a smokeless flame would be obtained which would give an illuminating power equal to slightly under 50 candles per 5 cubic feet consumed, and on reducing the size of the burner the illuminating power recorder would gradually decrease until with the No. 000 it would only be recording 35 candles per 5 cubic feet, this falling off being due to the cooling of the flame. It is manifest, therefore, that with such a gas the No. 0 burner would be the best at which to consume it in order to obtain the highest results from it; and when experimenting with illuminating gases of over 60 candle power it is impossible to get a burner which will develop the maximum value from the gas, as the burner has to be so small in order to prevent smoking, that cooling destroys a large percentage of the illuminating value. Hence it is frequently found that the enrichment value of a rich oil gas is higher than would be expected from its photometric value.

These facts have given rise to a process by which rich oil gas is mixed with oxygen, the presence of which, by increasing the rate of combustion, enables the gas to burn at a far larger burner than would be possible with oil gas alone, and an increase of sometimes as much as 25 per cent. in the illuminating value can be obtained. But such a gas would be useless for enriching purposes, as the oxygen which, with the rich gas, perfected the burner, and so gave an increase of illuminating value, would, when the gas came to be diluted with poor coal gas, overdo the combustion, and would cause a loss rather than a gain in

illuminating value—that is to say, that it would be far better to enrich the poor coal gas with oil gas alone than with a mixture of oil gas and oxygen, although the latter, *per se*, might show 20 per cent. more illuminating value in the photometer than the oil gas without oxygen.

In calculating the relative values of the two methods of oil gas making, the difficulty arises that, if the illuminating value of the two gases be taken from the photometric estimation, it is apt to be unjust to the richer gas. On comparing the following analyses of a 50-candle gas made by the Patterson process and a 60-candle made by Young's process:

	Patterson.	Young.
Unsaturated hydrocarbons	33·16	43·83
Saturated hydrocarbons	45·15	36·30
Hydrogen	19·85	16·85
Carbon dioxide	0·50	0·63
Carbon monoxide	0·50	0·00
Oxygen	0·60	1·14
Nitrogen	0·44	1·25
	100 00	100·00

it will be seen that the analyses support the recorded photometric observation which gives to the two gases the following values:—

Young's gas	100 cubic feet of 60 candle-power	=	1200 candles per gallon.
Patterson's gas	98 „ 50 „	=	980 „

or an increase of 22 per cent. in favour of the Young gas, which might probably be extended to 25 per cent. in enrichment. It is manifest that a gas of such high illuminating value would never be used *per se* except, perhaps, over small areas, where very high illumination was required, which even then would be more economically obtained by using a poorer gas in larger quantities. It may, therefore, be assumed that the future of oil gas will be purely for enriching poor coal gas and giving to non-luminous gases, such as hydrogen and carbon monoxide, illuminating power. The fundamental objections to oil gas for this purpose are, first, that its manufacture is a slow process, requiring as much plant and space for retorting as coal gas, and secondly, that although on a small scale it can be made to mix perfectly with coal gas and water gas, yet on the large scale great difficulties will be found in doing this, as although theoretically gases of such widely different specific gravities ought to form a perfect mixture by diffusion, yet in practice it would be found that layering of the gases would be very apt to take

place in the holders, and the liability to wide variations in the illuminating value of the gas sent out would increase.

Many gas managers have set their faces against oil gas as an enricher in the mistaken belief that it will not hold its illuminating value—i.e. is not so permanent—as coal gas; but this is not so, as well made oil gas depends far less upon condensable vapours for its illuminating power than coal gas, and will, therefore, lose far less of its illuminating value when exposed to cold or surface friction. The cost of such oil gas will be entirely dependent upon the situation of the works at which it is to be made, as this governs the price of the oil. Russian oil will cost a shade under 3*d.* a gallon alongside in most seaports, whilst the blue shale oil could be obtained at about 2*d.* at the works. But it is useless reckoning upon the latter oil in any very large quantities at this price, as its price is governed entirely by the price obtainable for the lamp oils and paraffin scale made at the same time, and the manufacture of any very large quantity of the blue or green oil would probably overstock the market with these and cause them to diminish in price, thus raising the cost of the intermediate product, so that for enrichment on the large scale it would not be safe to calculate the oil except in very favoured situations at less than 3½*d.* a gallon, at which price, taking into consideration fuel, labour, charge on plant, &c., a 60-candle oil gas would not cost less than 4*s.* per 1000.

The second class of gas substitutes consists of so-called air gas, which is either a mixture of air, carburetted with the vapours of highly volatile hydrocarbons, or else a mixture of oil-gas and air. The carburetting of air or poor coal gas by passing it over or through highly volatile hydrocarbons, such as the lighter naphthas and benzine, has always been a favourite idea of the processmonger, but with the exception of a few attempts to make small apparatus for use in country houses and institutions, no material success has ever been attained. The reasons for this are not far to seek. If air is used to carry the hydrocarbon vapours, the diluting effect of the nitrogen destroys the illuminating power of the gas with such rapidity, in proportion to the volume added, that any such process becomes economically impossible in practice, whilst when this trouble is got over by using combustible gases to carry the vapours, other and more serious objections arise, which have been fully exemplified in the numerous attempts made to carburet coal gas of poor quality.

The great trouble which in the past has presented itself in the various carburetting systems was, that all the commercial

samples of naphtha are mixtures of various hydrocarbons having each their own boiling point; therefore when used in any of the old forms of carburetter they gave up their more volatile constituents very freely at the beginning of the experiment, while the amount rapidly diminished as the boiling point of the residue became higher. Hence, when 2113 cubic feet of poor coal gas were passed through a naphtha having a specific gravity of ·869 and a boiling point of 103° C., the temperature during experiment being 22° C. (72° F.), the first 80 cubic feet of the gas took up 23·2 grains of the naphtha, whilst the last 450 cubic feet only took up 7·3.

The increase of evaporation with increase of temperature presented itself as another difficulty, for with an ordinary form of carburetter exposed to changes of the atmosphere the enrichment of the gas, which reached 44·4 per cent. in summer, the average temperature being 72° F. (= 22° C.), fell in winter to only 22 per cent., with an average temperature of 37° F. (= 3° C.). A good deal depends on the form of the carburetter. In an experiment in which gas passing through a box containing a layer of naphtha only took up about 3·2 grains, when the naphtha was sucked up by cotton fibres, owing to the large surface exposed the gas took up as much as 22 to 23 grains in the same period of time, the same naphtha being used in both cases. A most important point is that a poor gas only could be enriched in this manner, whilst a rich gas loses some of its illuminating power. The best method of carburetting poor coal gas at the burner at the present time is that known as the Albo-carbon process, in which solid naphthalene is vaporised in a chamber by means of a strip of metal kept hot by the flame, the vapour mixing with the gas passing through the chamber. During the past few years the idea of carburetting coal gas in bulk has again been revived by the construction of an ingenious apparatus devised by Messrs. Maxim and Clarke, which, to a great extent, overcomes the difficulties of the old forms of carburetter.

In carburetting a coal gas with naphtha or gasoline the more volatile portion enriches the gas to an undue extent at first and then, as the process continues, the amount taken up gets less and less. This would not matter so much in carburetting the gas in bulk, as the gas to a certain extent would mix in the holder by diffusion and a fairly even illuminating gas would be the result. The Maxim-Clarke process not only does away with the trouble, but carburets the gas used in large works and establishments so that each portion of the gas has its proper share of hydrocarbon. For small installations the apparatus consists of a circular copper retort, which is kept

automatically filled to a fixed level with gasoline from a reservoir outside the building. The retort is jacketed, and steam or hot water is passed round it which volatilises the gasoline; this passes over baffle plates in the top of the retort, and then through an automatic regulator into a small holder sealed with mercury. The gas to be carburetted has to pass through this holder, and as it does so the gasoline vapour is supplied to it in the following way:—The holder works on a vertical spindle which passes down the tube into the gasoline retort, and is so arranged that when the holder is grounded, i. e. when no gas is passing through, the opening is closed, and no gasoline can pass into the holder. As gas is admitted, the holder rises and lifts the spindle with it, allowing the gasoline vapour to rush up through grooves cut in the bottom of it, which increase in size the higher the spindle is drawn, and so allow more gasoline to pass into the holder the more gas passes through.

Admirable, however, as the Maxim-Clarke process is for adding two or three candle power to the illuminating value of a poor coal gas, experiments made by the author show that it is useless to attempt to enrich a non-illuminating combustible gas, such as water gas or hydrogen, to more than about 8 candle power by its aid, as any lowering of the temperature causes the volatile hydrocarbon vapours to re-condense, partly by the lowering of temperature and partly by the friction of the pipes and burners. It is manifest, therefore, that this second class of gas substitutes can at once be dismissed from consideration, as they could never enter into competition with coal gas.

The third and most important class of coal gas substitutes consists of carburetted water gas, discovered by Fontana in 1770, and first worked by Ibbetson in England in 1824. Up to 1858, however, all attempts to make and utilise water gas ended in failure. About that time the subject began to be taken up in America, and the principle of the regenerator, enunciated by Siemens in 1856, having been pressed into service in the water gas generator under the name of fixing chambers or superheaters, water gas gradually approached the successful development to which it has attained in the United States during the last fifteen years.

When carbon is acted upon by steam at high temperatures, the completed reaction may be looked upon as yielding a mixture of equal volumes of hydrogen and carbon monoxide, both of them inflammable but non-luminous gases. This decomposition, however, is rarely completed, and a certain proportion of carbon dioxide is invariably to be found in the water

gas, which in practice generally consists of a mixture of about the following composition:—

Hydrogen	48·31
Carbon monoxide	35·93
„ dioxide	4·25
Nitrogen	8·75
Methane	1·05
Sulphuretted hydrogen	1·20
Oxygen	0·51
	100·00

The ratio of carbon monoxide and carbon dioxide present depends entirely upon the temperature of the generator and the kind of carbonaceous matter employed. With a hard dense anthracite coal a temperature can be attained at which practically but little carbon dioxide is produced, whilst with an ordinary generator and a loose fuel like coke a large proportion of carbon dioxide is generally to be found. The sulphuretted hydrogen in the above analysis is due to the high amount of sulphur present in gas coke, and is practically absent from water gas made from anthracite, the nitrogen being the result of heating the fuel to incandescence by an air blast which leaves the pipes, &c., full of nitrogen and carbon monoxide called producer gas, which is carried over by the first portions of water gas into the holder. The constituents of the water gas so made are non-luminous, and attempts to use it as an illuminant have been in the direction of heating thin mantles or combs of refractory material to incandescence with it.

Many forms of generator have been used for the production of water gas, which, after or during manufacture, is mixed with the vapours and permanent gases obtained by decomposing various grades of paraffin oils and fixing them by subjecting them to a high temperature. These processes can be divided into two classes:—

1. Continuous processes, in which the heat necessary to bring about the interaction of the carbon and steam is obtained by performing the operation in retorts externally heated in a furnace.

2. Intermittent processes, in which carbon is first heated to incandescence by an air blast, and then, the air blast being cut off, superheated steam is blown in until the temperature is reduced to a point at which the carbon begins to fail in its action, when the air is again admitted to bring the fuel up to the required temperature, the process consisting of alternate formation of producer gas with rise of temperature, and of water gas with lowering of the temperature.

Of the first class of generator none have as yet been practically successful. Of the intermittent processes, the one most used in America is the Lowe, in which the coke or anthracite is heated to incandescence by an air blast in a generator lined with fire brick, and the heated products of combustion, as they leave the generator and enter the superheaters are supplied with more air, which causes the combustion of the carbon monoxide present in the producer gas, and heats up the fire-brick baffles with which the superheater is filled. When the necessary temperature of the fuel and superheater has been reached, the air blasts are cut off and steam is blown through the generator, forming water gas, which meets the enriching oil at the top of the first superheater, called the carburetter, and carries the vapours with it through the main superheaters, where the fixing of the hydrocarbons takes place. The chief advantage of this apparatus is that a low temperature can be used for fixing, owing to the enormous surface for superheating, and which to a great extent does away with the deposition of carbon. This form of apparatus has found its way into this country, and practically all carburetted water gas plants are founded upon the same set of actions.

The Springer plant has the superheater and fixing chambers arranged above the water gas generator, and an oil heater and vaporiser are also employed. The fuel is first raised to incandescence by an air blast, and the producer gas is used to heat the fixing chamber; steam is then blown down through the fuel in the generator, and the resulting water gas is partly led back again to the fixing chamber and partly to the oil vaporiser, where it helps to distil the crude oil and returns with the vapour to the fixing chamber, where the oil vapours are converted into permanent gases. The same idea of making the steam pass down through the fuel after the air blast has passed up is also to be found in the Loomis plant. It is a distinct advantage to do so, as the fuel is hottest where the blast enters, and in order to keep down the percentage of carbon dioxide the water gas must pass through as hot a fuel as possible.

The Flannery apparatus is only a slight modification of the Lowe. In it the oil is fed into the generator as the gas leaves it, and with the gas passes through a D shaped retort tube, which is arranged round three sides of the top of the generator. In this retort the oil is volatilised and is fixed in the superheater in presence of the gas. The Van Steenburgh system has a very distinct feature in that the top of the fuel itself forms the superheater, no fixing chamber being required. This reduces the apparatus to a very simple form, and one which is not likely

to get out of order or choke in any part. The drawback to it is that it is not suited for oils of a heavy specific gravity, so that very light oils only must be used in it for carburetting purposes.

Of these various water gas processes the only one which has attained to anything like continuous working in this country is the Lowe plant, of which there is a large installation at Beckton. The experience gained with several years working with this plant, shows that it costs about 2*s.* per 1000 cubic feet of 25-candle gas. The oil used is Russian solar distillate, having a specific gravity of ·860 and a flash point of 130° F. After the crude oil has been subjected to distillation and the light kerosenes and heavier lamp oils have been driven off, the residuum known as Astatki, which was formerly considered a waste product, is now subjected to further distillation, yielding the solar distillate and lubricating oils. On the price of oil the economy of a water gas depends, and as the American oils, owing to their low flashing point, cannot be used here, the Russian oils are practically those which must be employed. In considering the price of such oil in bulk, it is found that it costs 1¼*d.* a gallon to bring it from Baku and put it in the tank steamers at Batoum, whilst another penny a gallon is charged for conveying it to the Thames, but this would be considerably reduced by laying a pipe line from Baku to Batoum, and by increasing the number of steamers. But it must also be borne in mind that up to the present the distillers have been making hardly any profit on it, and we must, therefore, not expect the oil to be very much cheaper for some years to come. When bought by the shipload—2000 to 2400 tons—solar distillate costs the large London works which have facilities for water conveyance a little under 3*d.* a gallon, but at inland works 3½*d.* will probably be nearer the actual cost.

The author has been for the past two years trying various experiments with a view to devising a process for the manufacture of a carburetted gas which should embrace the following advantages:—

1. Rapidity of make and simplicity of working.
2. Compactness and cheapness of plant.
3. Reduction of the percentage of carbon monoxide to a minimum.
4. Decomposition of the oils so as to obtain the maximum illuminating value from them and the smallest amount of tar.
5. Making the gas of such quality and specific gravity that our present knowledge of rates or flow in mains, &c., shall still be available, and that no alterations in the method of consumption shall be required.

The first experiments were directed to making hydrogen as pure as possible, and enriching it either by the vapours of light hydrocarbons as in the Maxim-Clarke process, or by oil gas as made in the carburetted water gas process. The result of the experiments was that a gas could be made containing from 84 to 90 per cent. of hydrogen at a price very little above that of water gas. The apparatus employed consisted of a vessel charged with iron turnings surrounded more or less by a fuel chamber. An air blast raised the whole to incandescence, and the producer gas formed in the fuel chamber was made to pass through the vessel containing the iron. When the requisite temperature had been reached, the air blast was shut off and steam turned on to the iron. This yielded iron oxide and hydrogen by decomposition of the steam. When the evolution of hydrogen became slow, the steam was turned off and the air blast admitted, and the producer gas thus formed reduced the iron oxide back to the metallic state, and at the same time raised it to the necessary heat. The reduction of the iron oxide being thus effected in the apparatus, the plant could be worked continuously, doing away with the necessity of recharging the iron vessel.

The chief trouble in this operation was that the reducing blast carried over with it a quantity of fine carbonaceous dust, and also deposited a white powder, which on analysis proved to contain chiefly silica, magnesia and alumina. This was obviated by placing a layer or two of asbestos cloth above the iron, which could be shaken out after each day's work. Another important trouble was that the oxide of iron was sometimes fused by the high temperature, but the difficulty was got over by increasing the thickness of the wall dividing the iron from the fuel, by shortening the period of blowing, and by heating the iron chamber on one side only. After having made hydrogen of reasonable purity, it was found that it was not so well suited for the purpose in view, as loss occurred in storage owing to its high rate of diffusion, whilst as it formed a dangerous mixture with the addition of only a small quantity of air, it was not so safe to store as coal gas. Although these difficulties were reduced on carburetting it, yet it was soon found that much over 50 per cent. of hydrogen interfered with the rate of flow of gas and the size of the flame.

The next experiments were made with a view of producing a gas which should closely resemble coal gas in its composition, and at the same time meet, as far as possible, the requirements laid down by the author. As the result of these experiments, an apparatus was devised which could be used for manufacturing a uniform mixture of water gas, oil gas and hydrogen. This

apparatus consists of one generator containing three compartments, the central one filled with coke and the two sides with iron. The coke is raised to incandescence by air blasts, one of which enters at the bottom of the fuel and the other two-thirds up the fuel. The producer gas thus formed passes through the iron, and reduces the iron oxide back to the metallic state after each run. On the necessary temperature being reached, the air blast is shut off and steam is admitted at the bottom of the iron chambers. By this means the steam is decomposed into hydrogen with the formation of iron oxide, and at the same time that this is taking place crude oils are injected into the centre of the fuel by means of superheated steam. The fuel decomposes the steam into a mixture of hydrogen and carbon monoxide, whilst the oils are simultaneously decomposed or cracked, and are prevented from being burnt up by the protecting action of the water gas, which also allows them to be subjected to the high temperature necessary for their conversion into permanent gases. A second steam jet is placed below the oil injectors so as to rapidly sweep out the oil gas by means of a rush of water gas if necessary. The three gases, hydrogen, oil gas and water gas, are made to mix in the top of the generator, and thence pass on to be purified. When the temperature of the fuel has fallen too low for the production of gas, the steam is shut off and the air blast restarted.

Dr. Leonard Thorne, in his report upon this process, states that in his experiments with the apparatus, 1000 cubic feet of 20·7 gas were obtained by the consumption of 3·75 gallons of oil, but since then far higher results have been obtained, the daily working averaging 3 gallons of oil and 35 lb. of coke per 1000 cubic feet of 20-candle gas, whilst occasionally 22-candle gas has been obtained per 2·7 gallons of oil used for the 1000 cubic feet. This plant has only been worked occasionally on a small scale, and under very adverse circumstances. On analysis of the purified gas the following results were obtained:—

Hydrogen	40·77
Saturated hydrocarbons, methane, &c.	29·20
Unsaturated hydrocarbons, ethylene, &c.	14 21
Carbon monoxide	15·15
Oxygen	0·13
Nitrogen	0·54
	100·00

which shows that the carbon monoxide has been reduced to half the volume usually found in carburetted water gas.

The gas is made with the same rapidity as ordinary carburetted water gas, and great compactness is attained in the

apparatus owing to superheating chambers being unnecessary, and the space required for a generator to make 250,000 cubic feet per diem is only 18 feet by 7 feet and 10 feet high, the initial cost being also considerably less than that of any other plant. A bench of twenty-five coal retorts would cost about 2500*l.*, reckoning each retort to cost 100*l.* Each retort would generate 10,000 cubic feet in 24 hours, and twenty-five retorts would therefore yield 250,000 feet of gas per diem. The Lowe plant to make this amount would cost about 900*l.*, whilst the generator devised by the author would only cost about 550*l.* The specific gravity of the gas can be made identical with that of coal gas, thus requiring no fresh knowledge with regard to rates of flow, &c.

From the facts which the author has brought before the Members in this very imperfect review of the various processes which have been proposed for the production of a substitute for coal gas, it will be seen that none of them could, as regards cost, be commercially successful, with the exception, perhaps, of the class last mentioned, in which 20-candle gas could, in most localities, be made at a cost of 1*s.* 3*d.* per thousand in the holder. But even if this process were to be largely adopted, it would never supersede coal gas, as, unless anthracite coal could be cheaply obtained, the process would be dependent upon cheap coke. It could, therefore, only be used to advantage for the production of about half the normal output of a works, and should in this way yield many advantages, as it would prevent a fall in the price of coke, and from the rapidity with which gas can be made by it, would give the gas manager important aid in case of fog or labour troubles.

DISCUSSION.

The PRESIDENT said he had much pleasure in proposing a cordial vote of thanks to Prof. Lewes for his admirable paper, which was full of information and interest, and which he hoped would be fully discussed.

The vote of thanks was carried by acclamation.

Mr. W. R. HERRING said that as he had not heard the whole of the paper he would only deal with the following paragraph:—"These facts have given rise to a process by which rich oil gas is mixed with oxygen, the presence of which, by increasing the rate of combustion, enables the gas to burn at a far larger burner than would be possible with oil gas alone, and an increase of sometimes as much as 25 per cent. in the illuminating value can be obtained. But such a gas would be useless

for enriching purposes, as the oxygen which, with the rich gas, perfected the burner, and so gave an increase of illuminating value, would, when the gas came to be diluted with poor coal gas, overdo the combustion, and would cause a loss rather than a gain in illuminating value." He thought that that statement was a very sweeping assertion, and he was forced to come to the conclusion that Prof. Lewes had not had very much practical experience of the process. He (Mr. Herring) had devoted considerable attention to the oxy-oil gas for some months past. In December last he spent a week investigating the process at the experimental works of the Hydro Oxy Gas Patents Proprietary at Salisbury Square, London, which he had no doubt many of those present had both seen and tried. He would briefly refer to the results which he then obtained, and also to the results which had been obtained from practical working. In May of last year, by enriching a 14·5-candle power gas with 5 per cent. of oxy-oil gas, a gas was produced of 18·38 candles, or an increase of 3·88 candles or 26·7 per cent. In November of the same year a 15·12-candle power coal gas was enriched by the addition of 5 per cent. of oxy-oil gas, and produced a gas of 18·90 candle power, being an increase of 3·78 or 25·0 per cent. In December of the same year a 12·56 coal gas, enriched by the addition of 5 per cent. of oxy-oil gas, produced a gas of 16·61 candles, being an increase of 4·05 candles or 32·2 per cent. Those tests proved, and he was borne out by the above figures, that the poorer the coal gas the greater was the effect of the oxy-oil gas upon it as an enricher, and that was no more than might be anticipated. It was, however, very remarkable that the ratio of the increase in the results obtained, which he had just given, was very uniform in proportion to the luminosity of the original gas.

The next point to which he wished to draw particular attention was the permanency or otherwise of the gas. He found by experiment that it was greatly superior to gas enriched by cannel and ordinary coal gas. He had taken various samples of those different gases and sealed them up in a small gas-holder. Coal gas, after standing over water for six days, depreciated from 15·32 candles to 12·94 candles, losing 2·38 candles. Coal gas enriched by cannel, after standing over water for six days, depreciated from 15·43 candles to 10·93 candles, losing 4·50 candles. Coal gas enriched with 5 per cent. of oxy-oil gas, after standing over water for six days, depreciated from 15·39 candles to 13·88 candles, losing 1·51 candles. The conditions under which those durability tests were taken were, in his opinion, very severe, considering that the volume experimented upon, the exposure to the water surface, and the skin

of the gas-holder were out of all proportion as compared with practical conditions. In May of last year he commenced the erection of oxy-oil gas plant at the Huddersfield Corporation Gas-works. He adopted a retort which had been patented by the Northern Counties Company, who were working the oxy-oil process, but unfortunately the form of the retort was such that it did not permit of any expansion. It was a zigzag retort, with an ascension pipe back and front, and the expansion which took place was constantly springing the joint, and it was impossible to keep the apparatus tight. That difficulty was got over by devising a different style of retort altogether, which provided for the expansion that must necessarily take place. Those retorts had been working for a fortnight, and during that time 244,600 cubic feet of oxy-oil gas had been produced, which was equal to 5·96 per cent. of their make of coal gas on that particular section of the works. That was added to their make of coal gas, which was 18-candle quality. The result was that an increase of 5½ candles was obtained for the addition of the 5·96 per cent. of oxy-oil gas. Those results, as far as they went, overstepped the results obtained on a smaller scale, and he had anticipated that when they got to regular working they would do better than was done with the small experimental plant. He might add that, owing to the coal crisis, the gas experimented upon contained a larger percentage of cannel gas, owing to their running short of common coal. Prof. Lewes seemed to think that the process was really no good at all, but he (Mr. Herring), speaking from the experience he had already gained with the process, both experimentally and on a practical scale of working, was of opinion that there was not the slightest doubt that it was a distinct advance in the direction of enriching processes, and before long they would know more about it than they did at present. He had not the slightest doubt that the gas was permanent. No more condensation had been recovered from the syphons than under ordinary conditions of working, and that was water condensation rather than oil. It was also found that the gas did not fall in travelling through the distributing mains.

Mr. H. O'Connor said that unfortunately his work had only extended to the erection of the Lowe plant. But he noticed that Prof. Lewes had stated that the number of candles obtained from his apparatus worked out to about 1330 candles per gallon. Recently, in ordinary working with a Lowe apparatus at Beckton, something over 1300 candles had been obtained during short periods. With regard to the cost of erecting the Lowe plant, he should like to know what Prof. Lewes included in the 900*l*. The professor said that a generator on his own principle would cost about 600*l*. Taking the

same proportion—that was to say, including the shells, linings, fittings, valves, injectors, &c.—the cost of the Lowe plant worked out to something like 356*l.* instead of 900*l.* Of course, if the cost of the whole plant was included it would work out to something considerably above that figure, but he presumed that Prof. Lewes meant only the generator, the superheater and valves.

Prof. Lewes: The general fittings to the superheater.

Mr. O'Connor said that for the Lowe plant that would come to something under 400*l.*, according to the figures he had taken from the absolute erection of the plant.

Mr. Charles Gandon agreed with all that Prof. Lewes had said. During the last few years gas-makers had been endeavouring to supplement the means by which they could increase or maintain the illuminating power of the gas in the cheapest possible manner. In former years, of course, cannel coal had been largely used, but at the present time the price was outrageous. Then came the mineral oils, which gave them the hope that they could enrich the gas without cannel, and he still had hopes that it might be so. He had had a large experience, and had made many experiments with those oils, and he had tried running them into retorts, but with very unsatisfactory results. The conclusion he came to was that if distilled at a low temperature they recondensed, while if a high temperature was used they blocked up every pipe in the place. That was his experience twenty years ago, and he was still of the same opinion. He thought that they could enrich the gas with those oils, but they required great care. The water gas processes were all very pretty. He remembered going to see the Van Steenburgh apparatus, and it worked admirably, but still it did not work well enough to induce him to adopt it, and he might say the same with regard to all the other processes. He had seen the system adopted at Beckton, which seemed to work very well, but he believed the cost was considerable.

Prof. Lewes said that 2*s.* a thousand was accepted as the price.

Mr. O'Connor said that he had no objection to that price being taken.

Mr. Gandon said that the success of the process depended a great deal on the cost of the oil. He thought that oil presented a very great field for avoiding the use of cannel. Only the other day he had an offer made to him for some cannel, which was 10*s.* dearer a year ago than it was at the present time. Therefore he thought that they ought to turn their attention to oil—that they ought to try and make oil succeed, but there were no doubt many difficulties in the way. As to the oxy-hydro process, he had no doubt there was something in

that, but he had not been able to discover it up to the present time. It seemed to him that it was only possible to get carbonaceous matter out of the oil. If any quantity of oxygen was wanted it could be obtained from the air. There was no doubt that the oil process was reducing the price of cannel, and that was something to be thankful for. He had listened with great interest and attention to Prof. Lewes' paper, and he thought that that gentleman had done a very great service to the gas industry.

Dr. L. T. THORNE said Prof. Lewes stated that the addition of any oxygen to a heavy oil gas enabled the gas to be burned through larger burners than would otherwise be the case, and that in that way a 25 per cent. increase was obtained in the illuminating value from the oil gas so burnt. With that he agreed entirely, but the author went on to say that oxy-oil gas was useless for enrichment purposes. To that opinion he gave an emphatic negative. He had worked a great deal at the subject on a small scale, and he had obtained results which had left no doubt in his mind that, not only could it be used as an enricher without any loss of illuminating power, which Prof. Lewes seemed to insinuate, but that it could be used with a very great gain of illuminating power, and could be used as a very valuable and very important enriching medium. He did not intend to go into details on the matter, as before many weeks had passed he hoped to be able to lay before the gas world detailed results, and to go into the whole question more completely. He would only give one or two figures which led him to take an opinion diametrically opposed to that of Prof. Lewes, which he thought had been given in a rather *ex cathedra* manner.

Some time ago he made experiments for the purpose of testing, on the one hand the enriching power, and on the other the stability of oxy-oil gas. Working under conditions which were very disadvantageous to the production of the gas, he obtained a minimum of about 3½ candles increase by an enrichment of 5 per cent. oxy-oil gas. He did not think a practical gas manager would consider that a gas, an addition of 5 per cent. of which would give 3½ candles increase, was altogether useless. He would point out that the increase of 3½ candles was obtained when used with the Argand burner. With a flat flame the increase was much larger. The gas so enriched proved itself to be more stable than the poor coal gas that was enriched by it. The coal gas that he took for enrichment purposes varied in different experiments from about 12 to 15 candles value. He found on keeping the various gases in small holders over water and subject to great cold and variations of temperature, conditions that were rather severe, that the unenriched gas averaged a loss in

the course of about three days of 1·3 candle, that the same gas enriched with about 5 per cent. oxy-oil gas lost only ·95 candle, and when enriched with 10 per cent. the loss was only ·5 candle; so that not only was there no extra loss in the enriched gas, but there was actually a diminution in the actual loss of from 1·3 candle to ·5 candle.

Those results, it should be remembered, were obtained while working on a comparatively small scale, and under conditions which he believed then, and still believed, to be disadvantageous to the oxy-oil gas. Results, however, were now being obtained on a large scale, and although the plant was not yet quite in complete working order, Mr. Herring had been able to-night to give some preliminary figures which he (Dr. Thorne) believed to be approximate to the average working. He noticed that those figures gave a higher illuminating gain than he had himself obtained in the experiments previously mentioned, but he had always expected that when they came to work on a commercial scale and under more favourable conditions they would get better results. The results obtained on the small scale were, however, sufficient to make the process a valuable one to gas managers. Before long he hoped to be able to give further results of his own experiments, both on a small and on a large scale, and he was certainly inclined to think that Prof. Lewes would have to seriously modify his opinion before he next read a paper on the present subject.

Mr. T. S. Lacey, referring to Mr. Herring's remarks on the storing of coal gas, pointed out that it must not be imagined, because coal gas lost some of its illuminants when stored in a small holder over water at a low temperature, that anything like such a loss would occur under the ordinary conditions of distribution. There were two ways in which coal gas could be depreciated, namely by subjecting it to a very low temperature, or by passing it over liquids that would absorb some of the illuminants. It was not possible to make coal gas proof against loss from the effect of any temperature that could be applied to it, nor could it be made to resist the action of any absorbents with which it might come into contact, but he asserted that London coal gas was proof against the temperatures and absorbents met with in the course of its distribution to the consumer. With regard to the cost of producing oil gas by the Lowe process, he believed it had been reduced since Prof. Lewes had obtained his information. He thought Mr. Harris, who was present, could give the most recent figures.

Mr. C. Harris said that the cost of water gas made at Beckton was 2*s.* per 1000 feet, but it had been reduced to under 1*s.* 8*d.* per 1000 feet. He noticed that Prof. Lewes said that in the Lowe, Springer and other similar processes, a large

proportion of illuminating gas was swept out at the end of each run by the blast. That was not the case, as two or three minutes before the end of each run the oil was shut off, and before the air blast was put on all the illuminating vapour was swept out by the steam, and only a proportion of water gas was blown away by the blast. He noticed that in Prof. Lewes' apparatus the superheated steam was taken in half-way up the fuel bed.

Prof. LEWES: Only the proportion used for injection.

Mr. HARRIS: Prof. Lewes had mentioned that the whole oil gas plant of the Gas Light and Coke Company was under the supervision of Mr. Glasgow. He (Mr. Harris) in the interests of the Company, wished to state that Mr. Glasgow had erected a plant of 1,000,000 feet per diem. The Company's engineers had since erected, and were now working, a plant capable of manufacturing 9,000,000 feet per day.

Mr. GANDON asked Mr. Harris whether the cost of 1*s.* 8*d.* per thousand cubic feet included cost of distribution.

Mr. HARRIS: No, delivered into the holder.

Mr. WILLIAM SUGG desired to ask a question of Dr. Thorne, relative to what he stated with regard to the flat flame burner giving a light better than the London Standard Argand burner. He (Mr. Sugg) wished to know what was the relative size of the slit used in the flat flame burner, and the relative height of flame in the Argand burner with 5 cubic feet of gas. If the Argand burner was used for testing the quality of gases of which the illuminating power was unknown, it was necessary that it should always be brought up to a 3-inch flame. If that was done and the differences were corrected to the standard of 5 cubic feet, in all probability it would be found that the Argand burner gave the best result. It was a very uncertain thing to use a flat flame burner for testing the illuminating power of gas. The least alteration of the slit would make a serious alteration in the illuminating power. If an Argand burner were used with a 3-inch flame, it would be found that they could test the illuminating power of gas much more accurately than in the ordinary way, where 5 cubic feet of gas was burnt, whether it made more or less than a 3-inch flame. He had pointed out many years ago that the Standard Argand burner should always be used in that way. It was made for a 3-inch flame, and directly they got below or above it the conditions of the air supply were altered and the calculations would go wrong. It was possible that the difference Dr. Thorne obtained was obtained in that way, and he did not think that he could possibly get it otherwise. He would like to impress upon Dr. Thorne when he made his experiments again that it would be worth while to try it up to a 3-inch flame, and never to use a flat flame burner as a standard.

Dr. Thorne said that in the experiments he had made he worked exactly on the lines Mr. Sugg indicated, working with a London Argand burner and working with the 3-inch flame, getting the results in that way and calculating the quantities. He was afraid that the remark he had made with regard to the illuminating effect being greater with the flat flame burner was not quite clear. What he wished to say was, that if he burnt a gas in the flat flame burner in all cases he did not get as good a result as with the London Argand, but the same gas burnt through a flat flame burner showed a larger increase with the addition of the oxy-oil gas than it did with the Argand burner. That was to say, supposing a flat flame burner showed at the commencement about 9 candles for the 5 feet against the 12 candles of the Argand, the increase would be nearer 4 candles than 3½. The effect was more marked in the case of the flat burner than in the Argand. He believed that the explanation was simply that the flat flame was much less suitable for burning the gas to get the full illuminating effect than the Argand, and that that defect was somewhat remedied when enriched with the oxy-oil gas, so that the oxy-oil gas made the burner more effective for its purpose. He would also mention that in referring to the loss of illuminating power of the gas he did not in any way intend to represent that that large loss was a normal loss for coal gas under ordinary conditions. He merely gave this as the losses of the same gas before and after enrichment under the special and severe conditions to which he had referred.

Mr. Sugg said that what he wished to point out with regard to the slit of the flat burner was that they obtained a different result in illuminating power according to the width of the slit in the burner. The Argand burner was a fixed standard, and could not be altered, whereas a finer or broader slit could be used with a flat flame burner. Whether either one or the other was used, if the terms were not exactly the same for the flat flame burner as for the Argand the parallel did not work. That was one of the objections to using a flat flame burner as a standard. It depended entirely on the quality of the gas as to the size of the slit which would suit that quality. It was possible to give the quantity of gas burned a greater quantity of oxygen than was suitable for it. Thus if the slit of the flat flame were made finer the velocity of the 5 cubic feet per hour would be increased—a greater percentage of oxygen would be given to it.

Mr. J. T. Lewis asked the author whether he had had any practical experience of the results obtained and the methods adopted by some gas managers—Mr. Herring, of Dover, for instance—of injecting into the retort during the latter end of the charge some oils for enriching the ordinary coal gas.

Mr. PERRY F. NURSEY said that one point occurred to him in connection with the subject of the paper which had not been touched upon, and that was the difficulty of obtaining the hydrocarbon oils for the purpose for which they were required. That difficulty had occurred in numerous instances which had come under his notice during the last thirty years, more particularly in connection with liquid fuel furnaces. He had watched that question almost from its inception, when Richardson's petroleum furnace was started in Woolwich Arsenal. It always appeared to him that directly any particular system was proved to be a practical success the price of the oil went up and stopped the operations. He thought that from one point of view the devising of methods of using the oil was beginning at the wrong end. On the other hand, it was desirable to pave the way for using the oil when regular supplies could be obtained at a steady price. The primary necessity, however, was that every exertion should be made to procure an unfettered supply of the oil on reasonable terms, more particularly as it promised to be of such great benefit to the community, as no doubt it would eventually prove to be, as an important gas substitute.

Mr. FRANK MEAD said that the ground of the discussion had been rather restricted. So far as he could see, the real crux of the paper was in the gas that Prof. Lewes produced, which the author had shown was of very much greater value, if it was to be used at all for the manufacture of oil gas, than that which was produced by the Lowe or similar processes, and he took it that it was an extremely important point that the carbon monoxide should be reduced in the Lewes process to one-half what it was in the Lowe. If it answered to enrich coal gas with water-oil gas made by the Lowe process, surely it would answer quite as well or better if on a commercial scale gas could be used such as Prof. Lewes produced. All who knew Prof. Lewes might be assured that the analysis he gave was to be relied upon. He looked forward with interest to the results of the gas produced on a commercial scale. Mr. Gandon had mentioned that cannel had gone up to an outrageous price, so that it could not be used by gas managers, and that most managers had to be content with obtaining a less quantity of gas from common coal, or they had to adopt some method of enrichment. Most gas managers were so situated that they could not afford to burn cannel, and could not well afford to reduce the quantity of gas they produced from a ton of coal. A process of the kind considered in the paper would probably come in as a useful adjunct in such cases, but he could not conceive that it would ever be of universal applicability. It would never answer in certain situations, and unfortunately it was applicable only in conjunction with coal gas making. He should very much like

to see water gas making standing on its own bottom, so that they could ascertain correct results practically and commercially. So long as coal gas and water gas making were worked in conjunction with each other there was great difficulty in absolutely deciding the cost of the water gas as against that of the coal gas. With coal at its present inflated price, water gas would stand a very good chance in commercial competition, but when coal was obtainable at a low price there was no chance whatever for it, save as a means of enrichment.

The President said that the discussion had perhaps been confined too rigidly to the enriching of ordinary coal gas. He thought that the object of Prof. Lewes was to give some idea of an apparatus which would produce quantity as well as quality, and he thought that that had been lost sight of in the discussion, which had perhaps followed too much on the lines of technical enrichment. He was sure that the practical gas engineers present would agree with him that the time had arrived when it was necessary that they should find something more to rely upon than the ordinary method of making coal gas in retorts. Two months of every year they were called upon to produce an extraordinary quantity of gas, and he thought that if the making of coal gas could be supplemented by an apparatus which would produce 18 or 20-candle gas at about 1*s.* 6*d.* or 1*s.* 8*d.* per thousand, they would be not only justified, but called upon as engineers to take very seriously into consideration whether such an apparatus should not be introduced into their works. In America water gas was used entirely for the supply of some towns and villages, but, as was well known, there was a serious division of opinion between the advocates of coal gas and the advocates of water gas as to which was the cheaper or the better. In America, however, he thought water gas held its own, but he did not think in this country it could compete with coal gas, purely and simply as a matter of one against the other. He thought, however, that in conjunction with coal gas, used in the way he had indicated, it would form a great adjunct to most of the manufacturing stations in this country, for use as an enricher, by mixing it with the ordinary coal gas, or by producing it in quantity as well as quality at a time when it was so required.

Prof. Lewes, in his reply upon the discussion, said that he was glad to find that one paragraph at least in his paper had been successful in creating a discussion; and, in replying to the remarks which had been made, he would first deal with those of Mr. Herring and Dr. Thorne. Those gentlemen considered that his remarks upon the enriching value of mixtures of oil gas and oxygen were incorrect; and while Mr. Herring put this down to want of experience, Dr. Thorne considered that he (Prof.

Lewes) had been speaking *ex cathedrâ*. He would be very sorry for any Member of the Society to think that he would place even one paragraph in the paper without having some justification for it; and he thought he could show that he was neither speaking without experience nor without justification. He had experimented continuously with the enrichment properties of oil gas and oxygen for something like seven months; and although he found that, by mixing oil gas and oxygen, an increase in the illuminating value amounting sometimes to 25 per cent. could be obtained, yet, when this mixture was used for enriching poor coal gas, the enrichment obtained was not greater (and was often less) than when oil gas was used alone without oxygen. For some considerable time those experiments gave results which were most inexplicable and unsatisfactory. Sometimes the enrichment figures appeared to bear out the idea of the oxy-oil gas being more valuable than oil gas alone, while just as often the figures obtained showed just the opposite. These contradictory results continued until the mixtures were made in a small holder, and every particle of the gas from the holder was burnt out at the photometer; the readings being taken continuously throughout, and then the mean of these readings taken as the value of the gas. It was then found that the enrichment value of the oxy-oil gas was generally lower than the enrichment value of the oil gas alone; and still further experiments showed that this was due to the cause which he had given in his paper, and that the contradictory results before obtained had been consequent on the practical impossibility of obtaining uniform mixtures in the holder, owing to stratification and layering of two gases of such totally different densities.

The low temperature at which the oil had been retorted had been spoken of as being an important factor in the process. But he had a vivid recollection of a visit to Huddersfield, and of being shown the method by which the oil gas and the mixtures were made; and he had been surprised to find that the gentleman in charge of the plant insisted on the colour of the oil gas being chocolate brown, which every maker of oil gas knew denoted a high and not a low temperature. There was no doubt in his (the speaker's) mind, or in that of any one else who knew anything of the properties of oil gas, that, when made at this temperature, it was one of the most permanent of illuminating gases, and, as Mr. Herring pointed out, certainly far more so than rich gas obtained from cannel coal. He (Prof. Lewes) considered that, in the face of these experiments, he was perfectly justified in making the statement which he had made; and until those experiments had been disproved, he would continue to hold the same opinion as now. At the same time, his only desire was for scientific truth; and if Dr. Thorne

would make an oil gas, accurately test its illuminating value, then mix it with oxygen, again take its value, and then enrich poor coal gas of known value with it, and after that show him, by properly conducted photometric experiments, that the amount of light obtained by burning the whole of the enriched gas gave enrichment figures nearer to those of the oxy-oil gas than of the oil gas alone, he would be pleased to embrace the view taken by that gentleman. But Dr. Thorne must remember that photometry was a subject in which the burners employed and the methods of testing had a most important effect, and that in such experiments an absolutely reliable standard, such as the Dibdin 10-candle flame, must be used for burning throughout the whole of the experiments, while, in testing the gas, it should be burnt at a fixed height of flame, and the value calculated from the rate of flow. Mr. Herring gave them the figures for the working of this process for the past fortnight; and he (Prof. Lewes) had roughly calculated the candles per gallon that these figures presented.

Mr. Herring: I simply gave the figures of the working, which I got out very hurriedly this morning.

Prof. Lewes (continuing) said those figures came out almost exactly the same as the enrichment figures claimed for the Young process in the report made upon it by the engineer of the Leith Gas-works; and if that was so, the value of the admixture with oxygen did not in any way appear to be proved. In leaving that part of the subject, he must ask Dr. Thorne and Mr. Herring to pardon him if he believed in his own experiments rather than in theirs, and that they must also always remember that he was perfectly open to be convinced as to the error of his ways.

He would now pass on to the remarks made by Mr. O'Connor, who pointed out that, with the improved working of the Lowe plant, they were obtaining results as high as 1300 candles, and that this was practically the same as was obtained by the carburetted hydrogen apparatus. There was no doubt that the result of 1300 candles was very good indeed; but Mr. O'Connor would, he believed, also be willing to admit that, in the early working of the Lowe process at Beckton, figures far below these were obtained, and that it was only by perfecting the plant, and using the most suitable grades of oil that this result had been realised; while the figures he had given for the working of the carburetted hydrogen plant were obtained with an apparatus of small size, and endowed with almost every drawback that could be bestowed upon it. Even with this he had reached figures far ahead of those given, and he hoped, with the new apparatus which would be working in a few days at the Old Kent Road, to show results better even than the best he had

before obtained. It must be clearly understood, however, that he had no wish to underrate the Lowe process, which fully deserved the pre-eminence it had obtained in America, and the position it was now taking in this country; and if he could improve upon the results obtained by it, he would feel that he had done very good work. With regard to the cost of the plant, he had taken the Lowe figures for the generator, cracking and superheating chambers (as nearly as he could obtain them for this size of plant) from a paper by Messrs. Goulden and Paddon, read at the meeting of the Incorporated Institution of Gas Engineers in 1892; and he thought it must be manifest that the doing away with the big external superheating chambers, with their checker-work of fire-brick, must mean a great saving in construction. He wished to endorse the valuable remarks Mr. Lacey had made as to the testing of the stability of the gas, as the behaviour of an illuminating gas in a small holder, probably many times smaller in diameter than the mains through which the gas was passed in practice, gave them no indication as to what might be expected of that gas during distribution. Mr. Harris informed him that the Lowe gas had been made at the rate of a little under 1*s.* 8*d.* per 1000 cubic feet of 25-candle gas; and considering how soon this authoritative statement came after Mr. Methven's statement at the last meeting of the Incorporated Institution of Gas Engineers, and which was the one he had given in his paper, it must be admitted that they were making enormous strides at Beckton in the production of the gas. Mr. Sugg's remarks as to the importance of the burners to be used in gas testing, and the impossibility of getting flat-flame burners that could be relied upon for uniform results, would be fully corroborated by every one who had studied the question. For experimental work, there was no doubt that flat flames could only be used with extreme caution and great attention to the size of the slit or orifice. It was a well-known fact that flat-flame burners could be obtained in London which would develop nearly 3-candle power for each cubic foot of gas consumed; while they would not have to go far to find plenty of other burners which looked identical in construction, and yet did not develop 1-candle power of illuminating value for the same volume of gas consumed. These latter were largely employed because of their initial cheapness, being made in Germany at a low rate, and without any consideration of the value of the gas to be consumed in them.

Mr. Lewis had asked as to the results to be obtained by injecting oil into the retorts at the end of the carbonisation of the coal. There was no doubt but that this was an admirable device when the gas manager had no other means of enrich-

ment at hand; but there was no doubt also that it was a very crude and expensive method of getting the illuminating value out of oil, and probably a large percentage was lost.

Mr. Nursey had raised a most important question as to the price of the oil, and the probable rise which would take place if there were a large demand for it. He (Prof. Lewes), however, thought that in all probability an increase in the demand would not cause an increase in the price; for, as soon as the demand was sufficiently large, pipe-lines would be laid from the Russian oil fields to the ports, and the arrangements for shipping the oil largely augmented. Besides, it must be remembered that other oil fields were being opened up, and that, as soon as oil seriously interfered with the use of cannel coal, attempts would be made to compete with it, and, by so doing, if possible prevent the gas manager from embarking in the stormy ocean of experiment. Moreover, shale oil, and even certain forms of phenoloid oils would be thrown into the market at a sufficiently low rate to prevent any serious rise in the Russian oils.

Mr. Frank Mead had pointed out the importance of reducing the quantity of carbon monoxide, and said that he would like to see carburetted water gas in a position to be distributed *per se* during (say) a portion of the summer months, when the gas manager wanted time for reconstruction and enlargement of his works. He (Prof. Lewes) felt that if he could succeed (as he had done) in reducing the carbon monoxide to one-half, they had attained a safe limit; but unless anthracite could be obtained at a cheap rate at the works, it would never replace coal gas, as the coke was required as fuel for the generator. He also wished to emphasise the fact that there was no competition between enrichment processes such as the Young and Bell process and production processes such as the Lowe and his own, as the enrichment processes could at the most add some 6 per cent. to the volume of the gas, while the production processes could at a pinch make the whole of the gas required at the works—in this way proving of the utmost value to the gas manager when hampered by fog or labour troubles. In conclusion, he acknowledged the vote of thanks which the Members had accorded to him for his paper.

Mr. Herring said he would like to remark that he had been at Huddersfield for two years, and had never met Prof. Lewes there.

Prof. Lewes observed that the plant he had seen was a small experimental one in the house, he believed, of a Dr. Mackenzie; and that he certainly had not had the opportunity of seeing the plant which Mr. Herring had erected.

November 6th, 1893.

WILLIAM A. McINTOSH VALON, PRESIDENT, IN THE CHAIR.

COLLIERIES AND COLLIERY ENGINEERING.

By R. NELSON BOYD.

THE immense importance of coal to all manufactories and works connected with engineering, gives an interest to the consideration by civil engineers of any details relating to the technical development of the coal trade and colliery working, and the author hopes it is sufficient to justify him in bringing the subject before the Society of Engineers. The output of coal has now reached the enormous total of 181,786,871 tons in one year, valued at the mines at 66,050,451*l.*, and this immense quantity is raised and carried by rail, sea or canal to its destination under the management of civil engineers. To trace the growth of this enormous trade is itself a most interesting labour, but not the object of this paper. It may, however, be permissible to briefly refer to the early workings for coal in the days when steam engines and steam pumps were unknown.

The oldest coal workings still open to inspection are probably those of Ayrshire, which show that the old pits were circular and about 6 feet in diameter. The limit of depth of the workings was always a free water course, and the method of working was by pillar and stall; the pillars being 5 feet by 6 feet, and the stalls from 7 to 9 feet. In those days, probably the thirteenth or fourteenth century, the art of timbering was unknown, and the workers had to trust for safety entirely to the pillars. The means of raising the mineral out of the old and shallow pits was by a winch worked by hand, which also served to raise small quantities of water. In some of the old Scotch collieries women were employed to carry the coal up ladders in the shaft. The quantity of coal raised by these methods must have been very small, and owing to the want of means of transport the produce of the pits must have been mostly consumed in the district.

At a very early period coal found its way from the Tyne to

London, from whence it was supplied to the surrounding country. It is recorded in the Annals of Dunstable that Queen Eleanor, consort of King Henry III., had to leave the town and go to Sudbury Castle, in the year 1257, owing to the smoke produced by sea coal. The fuel does not at first appear to have been very popular in the capital, for in 1306 the nobles and commons assembled in Parliament complained of its use as a public nuisance, corrupting the air with stink and smoke, and it was prohibited in London by Royal Proclamation, which was confirmed in the following year by a commission of oyer and terminer. This little check did not, however, have much effect either on the development of the industry, which was governed by the improvements in working and the introduction of machinery, or the consumption in London, which was regulated by the growing dearth of wood and the need of some kind of fuel. The hand winch was succeeded by the horse whim or gin, the cog and rung, and the water wheel, all of which were applied to raising coal and water. An appliance called a bucket pump was next adopted for raising water, consisting of a series of flat buckets fixed on an endless chain, which passed round a shaft placed over the pit, and kept revolving by means of a water-wheel. But none of these primitive inventions advanced the coal industry with anything like the influence exerted by the early steam engines. Accepting as approximately correct the estimates of coal production made by the Royal Commission on Coal, which reported in 1871, we find the total production of coal in 1600 to have been 2,148,000 tons, and in 1700, a century later, 2,612,000 tons, being an increase of 464,000, whereas the estimate for 1750 is 4,773,828 tons, or an increase of 2,161,828, equal to nearly cent. per cent. in the 50 years, during which Savary's and Newcomen's so-called "fire" engines were introduced. The impetus to the coal industry by the application of these machines was enormous. Coal seams, which could not be worked owing to water, were pumped dry, others lying at depths beyond the power of the horse whim were sunk down, and generally the coal mines were more extensively opened out and worked, owing to the possibility then afforded of raising more coal out of each shaft.

It may, perhaps, be permissible here to point out how many important machines, inventions and engineering appliances have been originated either in mines or for the use and benefit of working them. Savary's steam engine was most distinctly invented with a view to use in mines, and in the "Miners' Friend," published in 1702, he points out the economy of his engine for pumping water out of the Cornish mines, and writes: "be the mine ever so deep, each engine working 60, 70 or 80

feet high by applying the engines one above the other." Savary's lift was 30 feet for each engine, and this is the reason his invention was not more used for the purpose for which he had invented it.

Later on, in 1705, Newcomen obtained his patent for an improved engine, which was the forerunner of Watt's engine and the steam engine of the present day. Railways, as we shall see, had their origin in the coal pits, and the locomotive was invented, or perhaps, more accurately stated, was made practically applicable at a colliery, and it is just possible that the first idea of using the gas distilled from coal for illuminating purposes may have been suggested by the burning of what is technically termed a "blower" underground. But to revert, the "fire" engine held its own for about a century, when James Watt introduced his improved steam engine, which gradually replaced it. For many years after the introduction of this engine the Newcomen engine was in use, and even in recent times a few of them were still in work. Probably the first "fire" engine erected in the north of England coal field was at Byker colliery in 1714, and in 1721 it was in general use for pumping, and a few years later it was improved and employed, not only for pumping, but also for drawing coals. Very powerful engines of this kind were constructed, as, for instance, one at Walker colliery, erected in 1763, with a cylinder 74 inches diameter and 10½ feet long, and another erected by Smeaton in 1775, at Chasewater. The first advantage of the steam engine in mines was felt in pumping; even Savary's engine with its short lift had a useful effect. The pumps used in those days were the ordinary lift pump, and the engine was applied direct. Subsequently the rotary engine was introduced, and eventually the engine was placed underground and the water forced up in one column for very great heights. In modern pumping engines for mines, placed on the surface, the piston rod is connected direct with the pump rods by means of T bobs, and high-pressure steam is used. The latest pumping engines erected in the north of England are on the Cornish principle, and at the Throckley colliery a vertical compound beam rotative engine of the London water-works type has been adopted. This engine was erected in 1886 by Messrs. James Simpson & Co., of London, to lift about 2000 gallons per minute from a depth of 360 feet.

The introduction of the steam engine caused a great increase in the output of coals, and with this increase came the necessity for devising some improved means of transport. Already in the middle of the seventeenth century coals were conveyed from the mines to the banks of the river Tyne by laying rails

of timber, on which were run carts of great size, made with rollers or wheels fitting the planks, and by which four or five chaldrons could be drawn by one horse; and here we find the first inception of the railway. These crude wagon ways were soon improved by the introduction of cross sleepers to tie the planks, and eventually the latter were replaced by cast-iron slabs or trams, so called after the inventor, Mr. Outram. They were first used at Coalbrookdale in 1767, and subsequently adopted in the collieries of the north of England. These tram rails led by a succession of improvements and developments to the edge rail, and eventually to the rail now in use, not only in collieries but on the vast network of railways in this and other countries. The great development of collieries led also to increased dangers in working, among which the most prominent is perhaps the greater production of explosive gases owing to the nature of the deeper seams, and the increased face of coal exposed by extended workings. The terrible gas explosions which occurred from time to time, after the introduction of the steam engine in the beginning of this century, led to several ingenious inventions and appliances. Among the former the safety lamp is pre-eminent. The steel mill which had been in use for giving light in an explosive atmosphere since 1760, gave an unsatisfactory light, and, moreover, was known to be not quite safe. The attention of scientific men was directed to the construction of a lamp that would burn and give light with safety in an explosive atmosphere, and the result was the invention of the miner's safety lamp. The first one introduced was that of Dr. Clanny, of Sunderland, who described his inventions in the 'Philosophical Transactions' in 1813, and this lamp in an improved form is in use to this day. The next lamp tried was that invented by George Stephenson, then colliery engineer at Killingworth, and this lamp is also in use at the present time. In the same year that Stephenson's lamp was brought out, namely, 1815, Sir Humphry Davy invented the lamp which bears his name, and which, on account of its simplicity and light weight, soon became more generally adopted at fiery collieries than either of the others. Many other miner's lamps have been invented and introduced in collieries since Davy's time, in order to meet the dangers of swift currents of air underground. Thus the experiments made for the Royal Commission on Accidents in Coal Mines, which reported in 1886, showed that the Davy lamp fired an explosive mixture having a velocity of 400 feet per minute. The Clanny was useless in a current of 600 feet, and the Stephenson in one of 800 feet per minute. The best lamps, according to the experiments, were found to be the Gray, the Marsaut bonneted, the Mueseler, and the Evan-

Thomas-Clanny. The swift currents of air underground were the result of improved ventilation.

In former days, and up to the middle of the last century, the only system of ventilating coal pits was by natural ventilation, that is, by means of two or more shafts or openings, and trusting to a natural current of air; but as the mines became greater in depth, and larger areas had to be worked out of each shaft, mechanical ventilation had to be adopted. The first method introduced was to apply heat to one shaft and thus create a continuous draught as in a chimney, and this was denominated the upcast shaft. In shallow collieries, such as were common in Staffordshire, a grate was let into the brick-work of the upcast shaft, and the men in ascending occasionally threw a lump of coal on the fire. This was the most primitive mode, and was only applicable to limited workings, where small quantities of air were sufficient. In the larger collieries of the north of England proper furnaces were constructed at the bottom of the upcast shaft, and as the air drawn from the workings of the mine was frequently charged with so much gas as to become explosive when in contact with a flame, the return current was let into the shaft some yards above the furnace by means of a separate gallery called a "dumb drift," and the furnace was supplied with fresh air from the downcast shaft. As the shafts increased in depth, the cost became greater, and very large sums had to be expended on the sinking of a single pit. The Monkwearmouth pit in Durham was sunk in 1834 down to a depth of 575 yards, and is reported to have cost over 80,000*l.* In view of the cost of deep shafts, the plan of dividing the pit by means of 3-inch planking, called a "brattice," was introduced, so as to provide a downcast and upcast current in the one shaft, and this system generally prevailed at all deep collieries until 1862, when, after the memorable and terrible accident at the Hartley Colliery, by which 204 lives were lost through suffocation owing to the destruction of the brattice by the breaking of the beam of the pumping engine, part of which fell into the pit, an Act of Parliament was passed prohibiting collieries being worked without at least two means of exit for the men.

Among the absolute requirements of modern collieries is that of efficient ventilation. The danger of the furnace gave rise to numerous mechanical inventions for creating a sufficient current of air in the underground workings. In the early part of the century experiments were made with air pumps and fans, but they were not sufficiently successful to supplant the furnace, approved of as it was by the great north country viewers, who based their support, not to say prejudice, in its

favour on years of experience. Although the furnace continued to be the general, if not the only, method of ventilation in the north of England until a comparatively recent date, Struve's air pump cylinders were erected in considerable numbers in South Wales. Struve's air pump was succeeded by a variety of fans invented by Nasmyth, Biram, Brunton and others, and made of considerable size, even up to 14 and 15 feet diameter. In the north of England the introduction of the fan dates from the exhibition of 1862, when Monsieur Guibal, of Mons, in Belgium, sent in a drawing of his fan, which is centrifugal.

The centrifugal ventilators made great way even among the collieries of the north, and they have been constructed of very large size, up to 50 feet diameter, with a breadth of 14 to 16 feet. They are so economical in working that in a short time the heavy cost of construction is compensated for. The centrifugal ventilating fans which have met with the greatest success are the Guibal, the Schiele and the Waddle, and these, if well constructed, can be made to produce a ventilating current up to 250,000 cubic feet per minute. Taking one instance, a Waddle fan 45 feet diameter, at Newbottle Colliery, gives a current equal to 150,000 cubic feet per minute. Specially constructed furnaces for the ventilation of deep shafts, with fire grates having a surface of from 50 to 200 square feet, and fed with fresh air from the downcast shaft, are capable of giving from 200,000 up to 400,000 cubic feet per minute, but the consumption of coal is something enormous.

The gradual development of the coal trade brought with it the necessity for improved means of transport, both above and below ground. The question of conveyance is a vital one to the economical, or it might be said the possible, working of coal. Every kind of conveyance has been from time to time applied in coal mining, from the backs of women, in Scotland, up to the electric locomotive as now introduced in some mines in Germany. At first the coals were carried, then moved by wheelbarrows, afterwards drawn along the wagon ways in sledges, then the rail was introduced, the motive power being men or horses, but in or about 1855 the steam engine was applied underground for haulage purposes. This was rendered possible by the invention of wire ropes, which were first used at the mines of the Harz district in Germany, and introduced into England in 1834. They were at first made by hand in short lengths of 300 feet, but in 1840 a machine was constructed by Mr. Newall, and since then they have been manufactured by him and others in any required lengths. Their introduction into collieries for hauling purposes dates from 1855, or thereabouts, and in 1867 a committee of the North of England

Institute of Mining Engineers made an exhaustive report on the subject, and since then iron or steel wire rope haulage has been much improved and generally adopted.

The conveyance of coal underground here referred to, brings it to the shaft bottom, and it is needful to say a few words on the subject of raising the coal out of the pits to the surface. In the early days of coal mining the coal was carried up the shaft by hand, and even as late as 1842 women, called bearers, were so employed. When mechanical power was first introduced the coal was raised in buckets, and in the North in corves, which were huge wicker baskets fixed to the end of the rope and drawn up loose in the shafts. In South Staffordshire, until quite recent times, the skip was in use, being a small trolley on which the lump coal was packed by hand and held together by a series of iron rings or hoops. In the case of small coal these rings were placed one on the top of the other so as to form a sort of tub or case. These buckets, corves and skips come up swaying to and fro, often knocking the sides of the shaft and spilling some of their contents. In the North, where the advantage of raising as much coal as possible out of each shaft was first recognised, double ropes were introduced, one up and one down, and at meeting points the engine had to be slackened or stopped to prevent accidents, and frequently not one but several corves were raised at a time, one over the other, and when reaching the pit top had to be pulled over to the side by the banksman. In the case of skips a platform on wheels running on rails was pushed over the pit top on the skip reaching the surface, on which it was lowered, the empty skip being ready for hitching on to the rope.

The old shallow pits were round and from 6 feet to 12 feet in diameter, and lined with timber. This mode of lining consisted in putting cribs of oak at intervals of 2½ to 3 feet, and spiking 2½ to 3 inch planks on these cribs. In 1795 cast-iron tubbing in circles was used for the first time at the Walker colliery, and in the following year cast-iron segments were used for tubbing at Percy Main Colliery. Since then it has been the universal practice in the North of England to line the shaft near the surface with cast-iron tubbing, in order to dam out the water, the rest of the pit being lined either with stone or bricks. In the North and Midlands the shafts, as a general rule, are round, from 10 to 20 feet in diameter, but in some cases they are oval in shape, which is more easily divided, and was formerly adopted to provide for an upcast and downcast in the same shaft. The conveyance of coal up the shaft has undergone successive improvements. The corve and skip have been replaced by the cage and guides. This was the invention

of Mr. Carr, a colliery manager at Sheffield in 1795, who first began by drawing up small wagons holding from $5\frac{1}{2}$ to 6 cwt. of coal attached to the rope by means of chains, and this led to the introduction of conductors in the shaft to guide his wagons. These he describes as consisting of upright rods of deal, 4 inches by 3 inches, fixed on opposite sides of the pit, and forming mortices or channels by which the corves or tubs are guided, being suspended on cross bars with rollers at their ends, which run within the mortices. This idea led to the introduction of cages to hold these tubs. The introduction of cages and guide rods or ropes in or about 1830 in Yorkshire was a great improvement. It was not until 1836 that they were introduced into the northern district at the South Hetton Colliery, but they soon became universal, and at present it is not unusual to find cages carrying up to eight tubs in three or four decked cages, raising from 3 to 4 tons at a time. In order to lighten the weight to be raised, the ropes are now, and have been for some years, made of iron or steel wire, and in deep shafts a flat steel rope, tapered at the ends, is sometimes used. About twenty years ago the flat link chain with wooden wedges was still in use in South Staffordshire, a rude, cumbersome and extremely heavy contrivance. In order further to lessen the work of the steam engine, various modes of counterbalancing the weight of the steel rope are now adopted. The tendency has been in every direction to seek economy of working, either by the introduction of new mechanical appliances or by an improvement in the old methods.

The system of working coal at the face has not much changed, but it has been improved. In past days the pillars, amounting to one-third or more of the coal raised to the surface, remained in the pit and were lost. Even in recent times this method was followed, and the author has personal recollection of the working of the 10-yard coal in South Staffordshire, where, owing to the great thickness of the coal, timbering was difficult and expensive, and thousands of tons remain at present in the shape of pillars in the old drowned-out pits in that district. Many of these pillars are being worked at the present time, in consequence of the water being drawn off and pumped by the South Staffordshire Mines Drainage Association. In later years the 10-yard coal was worked under a modified plan, by which the upper part of the thick coal was first worked on the long wall system, and subsequently the lower part of this big bed, leaving a band or bench of coal between the lower and upper workings. This method was less costly and less dangerous, and enabled more coal to be raised per acre. The long wall or continuous face method was first adopted in the

thin seams of the central coal fields, and applied also in the Forest of Dean and in South Wales. This method is certainly the simplest, and offers the advantage of direct and easier ventilation. It was at first assumed to be only applicable to thin seams with a moderately good roof, but eventually it was applied to seams of 12 and 14 feet thickness with weak roofs, and as already stated, to the half-thickness of the 10-yard coal. Besides these two distinct methods there are modifications of the pillar and stall method in use in certain localities, such as the double stall used in South Wales, and the board gate and bank as found in Yorkshire. It may be recorded that no special new plan has been introduced since the beginning of coal mining. In the North of England the pillar and stall is still in use, but instead of leaving pillars as small as possible, which were afterwards only partially worked out, and then a good deal crushed, the modern system is to leave pillars 20 and even 40 yards square, which resist the pressure of the roof and are subsequently worked away by the long wall system.

The method of working coal includes the subject of cutting the coal down. The tool generally used is the time-honoured double-headed pick which, in the hands of a good collier, has defied innovations. With this he undercuts the coal and then breaks down the superincumbent mass either by wedges or by some explosive. Before the introduction of gunpowder the wedge was the only tool used, then came the more expeditious method of breaking down the coal by means of shots placed near the roof, but this proved a dangerous practice in fiery collieries, and the use of gunpowder is at present disallowed by Act of Parliament, except under strict regulations as regards safety. This has led to the invention of a variety of appliances for breaking down the coal without the use of gunpowder. One of the earliest of these was the old wedge forced in by hydraulic pressure. This was used at collieries in Staffordshire for some time, but abandoned as too cumbersome, and requiring a large outlay for the transmission of the power. Soon afterwards the lime cartridge was discovered and was very well received and extensively tried, but it was soon found that the power was not great, and to do any work the lime had to be practically quite fresh, and its use after a short time was abandoned. Improvements in the method of breaking down the coal have of late led to the production of a flameless explosive. The commissioners on accidents in coal mines, who reported in 1886, recommended high explosives, such as dynamite, blasting gelatine, gun-cotton, or tonite mixed with water, and expressed the opinion that the use of gunpowder and similar explosives should be prohibited. They further recommended that in all

cases where gas exists, firing by electricity instead of by fuse should be adopted.

In recent years the Sprengel class of explosives, so called after the inventor, have been greatly improved, and a new series of chemical explosives, mostly based on ammonium nitrate, have been used, some of which possess the desired quality of exploding without flame, that is if used in a proper manner. Mr. J. C. Butterfield, in referring to a number of experiments with different explosives made under his direction, says:—

1. That none of the explosives used were flameless when untamped.

2. That gunpowder, even when tamped with 15 inches of clay, was unsafe.

3. That roburite and ammonite when tamped with not less than 8 inches of wet clay were perfectly safe.

4. Securite, dynamite, tonite and carbonite, under similar conditions, were not safe. From this it appears that the firing of shots with safety in coal mines to bring down the coal, is a desideratum which has yet to be realised.

The question of undercutting the coal by machinery has been very much considered, and numerous machines for the purpose have been invented and tried. The first machine was probably Mr. Frith's pick machine, driven by compressed air, which was introduced at the Hetton colliery in 1863, and one of the most recent is the electric coal-cutting machine brought out in 1887 by Messrs. Bower, Blackburn and Mori. This consists of a frame travelling on wheels carrying a specially designed electric motor driving a shaft which carries the cutter attached by bolts to a coupling. This cutter consists of a bar carrying a series of star-shaped cutters specially formed. The whole motor and the shaft carrying the cutter bar can be rotated in a horizontal plane for the purpose of bringing the cutter in and out of the coal. The cutter is revolved by an electric motor at the rate of about 600 revolutions per minute, and the motor develops a power of 6 to 9 actual horse-power, according to the hardness of the seam. When cutting is commenced the motor is started, and the turntable rotated by a worm wheel till the cutter has swept through a right angle and is 3 feet 6 inches deep in the coal. It is then drawn along the face by a winch, under or overcutting the coal to that depth. The actual work effected by this cutter has been 45 yards in an hour, including all stoppages. The power is transmitted from dynamos on the surface by means of two cables. The electric coal-cutter has not had time to become established as a success; and in general use, certainly no coal-cutting machine has as yet proved

universally applicable, although there are some machines in daily use in different districts. It would seem that the different peculiarities of various coal beds as to thickness, hardness, inclinations and so on, almost require a different kind of machine for each bed.

The result of past experience with coal-cutting machinery is aptly stated by the President of the North of England Institute of Mining and Mechanical Engineers, who, in referring to these machines in 1892, said: "The substitution of machinery for hand labour in hewing coal, introduced many years ago, does not seem to have made much progress." So that the collier and his pick still remain at the face of coal as in by-gone days, while every other department of a colliery has been improved and made more efficient by the introduction of machinery. Of late years the great extension of the underground workings has prominently raised the subject of transmission of power. There are points in an extensive coal mine at considerable distances from the shaft where power is required for a variety of purposes, such as hauling up a staple or incline, or pumping water, or working a coal-cutting or drilling machine or a ventilator, and the subject as to the best means to be adopted for the transmission of power may be considered as the question of the day so far as collieries are concerned. The methods which have to be studied and compared as to their efficiency are transmission of power by steam, by ropes, by compressed air, by electricity, by petroleum or gas engines and by other means. The results obtained by these diverse systems have not yet been sufficiently definite to enable a decided preference to be given to any of them. But it seems as if for this purpose electricity will gain the day. At any rate, so far the results have been favourable. Steam and compressed air have been in use for some time, but are expensive on account of the loss in transit. Ropes give very good results but absorb much power through friction if they have to be carried round and over many bends. Petroleum and gas engines remain to be tried, but an obvious objection to their introduction in a fiery pit is their danger. Electricity has been objected to on the same grounds, but with careful arrangements the transmission is practically safe.

As an example of the progress that electricity has already made, as applied to the transmission of power underground, it may be interesting to give a description of the electric plant in use at one of the Earl of Durham's collieries, which is, perhaps, the largest applied to mining. The engines are of the Willans high-speed type, two in number, and equal to 140 horse-power each. There are two dynamos, each capable of

giving 80 ampères at a pressure of 780 volts and running 500 revolutions per minute, and equal to 84 electrical horse-power each. They are separately magnetised by a small dynamo, which is also used for lighting, and is capable of 90 ampères at 100 volts and 1200 revolutions per minute. In addition there is a fourth dynamo with 120 ampères at 100 volts, which is used for lighting and magnetising. The current is taken down the shaft and run a distance of 387 yards to the distributing centre. Here the cables branch: one is run another 670 yards to a pump; another circuit runs 1290 yards to the hauling engine, and 1500 yards further to a winding engine to draw up a staple 144 feet deep. Electricity has to overcome a certain amount of prejudice and a good deal of apprehension as to danger on the part of colliery engineers, but it appears to be making headway as a transmitter of power. For illuminating purposes underground it has so far not proved a great success, and a practical miner's electrical lamp remains to be invented.

The effect of the increased introduction of machinery in collieries of late years may very well be judged by a table prepared by the Royal Commission of 1886. Among other information this table shows that between 1873 and 1884 the number of boys aged from 12 to 13 years, mostly trappers or horse boys, diminished from over 11,000 to 3364, having been replaced by mechanical appliances for ventilation and steam traction; and that the number of youths from 13 to 16 years of age has diminished by nearly 6000, and these, probably hurriers or drivers, have also been replaced by steam traction, whereas the men above 16, including, of course, hewers, timbermen and watermen, &c.—in a word, colliers in the full meaning of the term—have remained nearly stationary in numbers. In fact machinery, which has done so much for the transport of the coal and the ventilation of the mine, has affected the work of the hewer very slightly. This table is ten years old, but it may be accepted as certain that the same ratio of coal raised to different classes of labour has been maintained in subsequent years.

The interest of the engineer in the coal industry does not end with the raising of the mineral. In 1892, 181 million tons of coal were raised, which then had to be handled on the surface. Approximately 130 million tons were transported over the various railways, and for an average distance of say about 30 miles, which is equal to 3900 million ton miles. About six million tons were transported by canal, and the balance loaded direct into ships for the foreign and coasting trade.

The reference to the enormous quantity of coal we are now raising in the United Kingdom brings us to the consideration of the duration of our coal fields, if the production is to con-

tinue at anything like the present output. This is not by any means a new question. It has a history and a past. Mr. R. Bald, a Scotch colliery engineer, writing in 1812, in referring to the eventual exhaustion of the coal fields, says: "Even if the Grampian Mountains were composed of coal we would ultimately bring down their proud and cloud-capped summits, and make them level with the vales." Years before Mr. Bald wrote, the inevitable exhaustion of the coal fields had been admitted by thinking men, but the subject did not appeal to popular reflection, and those more intimately connected with the coal industry were of opinion that the quantity of coal in reserve was so large that the question of its exhaustion might very well be left to the consideration of future generations. It was not until the publication of Professor Hull's book on the coal fields of Great Britain in 1861 that any serious attention was given to the subject. At the meeting of the British Association for the Advancement of Science, at Newcastle-on-Tyne in 1863, Sir William Armstrong, the President, referred to the subject, and startled not only his audience, but the whole country, by alluding to the possibility of the coal supply being exhausted in a couple of centuries. In 1865 Mr. Jevons, basing his calculations on the data of Mr. Hull, and taking the ratio of increase in production as equal to that of previous years, predicted the exhaustion of coal in Great Britain in 110 years. Public attention was now aroused, and the subject became a topic of discussion in the House of Commons. Mr. John Stuart Mill was the first to allude to it in Parliament. Mr. Gladstone mentioned it in his Budget speech of 1865, and a long debate took place on the 12th June, 1866, when, at the instance of Mr. Hussey Vivian, a Royal Commission was appointed to investigate the probable quantity of coal existing, to inquire as to the quantity of coal consumed in the various branches of manufacture, whether any waste takes place in the working, and other matters.

This Commission, appointed on the 28th June, 1866, reported in July 1871, having during the time made most searching and complete investigation of the subject. They made no definite estimate of the duration of the coal fields, but suggested three alternatives, leaving it to the reader to adopt that which most appealed to his comprehension. They estimated the total quantity of coal available at 90,207 millions of tons in the known coal fields down to a depth of 4000 feet, and estimated the total reserve at 146,480 millions of tons, including the seams lying beneath the Permian and other younger formations. Taking the former figure, the Royal Commissioners estimated first: That on the basis of diminishing

ratios of population, the reserves would last 360 years. Secondly, assuming a yearly increase in the production of three millions of tons, the term would be 276 years; and lastly, supposing the population and consumption of coal to remain constant, the supply would extend to 1273 years. Since the publication of the report various estimates have been put forward. Mr. Price Williams estimates the duration at a little over 100 years, taking the increase at the rate of $2\frac{1}{2}$ per cent. per annum. Prof. Marshall, taking the rate of increase of output from 1854 to 1876, estimates the duration at 125 years. But these estimates are all more or less leaps in the dark, because the basis of calculation is uncertain. In the first place, the estimate of quantity is open to correction, as we may discover more coal under the Permian and other newer formations than the Commissioners allowed for. The depth of 4000 feet is attainable, because there are at present collieries working near Liège, in Belgium, down to a depth of about 3500 feet; but we can only surmise what the yield of coal will be at that depth in Great Britain. Assuming, however, that the estimate is practically correct, it is worth recording that the Commissioners' estimate of an increase at the rate of three million tons a year has been very nearly borne out by the output up to last year. They estimated in 1871, when the output was 113 millions of tons, and if we add to this an increase of three millions of tons for 20 years, say 60 millions, the estimated amount would be 173 millions of tons, and the exact amount raised in 1892 was 181 millions of tons. Taking these figures, our coal supply would last for 276 years, but this does not mean that at the end of that period we shall have no coal.

It must be borne in mind that, firstly, coal will become dearer as we get deeper, and hence a necessity for economy will arise; secondly, that the field of invention is open in that direction, for it may be accepted as a fact that we do not derive more than 5 per cent. absolute caloric value out of the burning of coal in all its appliances, from the steam engine to the household hearth; and, thirdly, other sources of heat will be introduced long before the time comes for shutting down the last colliery. Already we are importing petroleum residue for the manufacture of gas. The quantity used for this purpose in 1892 amounted to about 20,000 tons, equal in heating efficiency to 40,000 tons of coal. Liquid fuel is regularly used on the Great Eastern Railway in this country, and would be very largely adopted if a supply could be obtained, and this is only a matter of time required for the education of capitalists to the advantage and profit to be derived from this fuel. The supply can be easily realised. Then, again, there is the question of peat,

which only requires the invention of some practical machine to extract the great percentage of moisture it contains in a satisfactory manner. The vast stores of peat in different parts of the country, more particularly in Ireland, ought to provide a considerable amount of fuel.

In conclusion, the author would observe that he has not attempted in this paper to do more than trace the development of the coal industry. In the beginning of this century the quantity of coal raised amounted to about 10 millions of tons, as estimated by the Coal Commission, a figure which may be accepted as very nearly correct, and last year, that is to say, near the close of the century, the quantity raised reached the enormous figure of 181 millions of tons. In former years the coal mines were wrought in the crudest manner, and by men who had but little technical education of any kind, but as the extension of the workings took place, and the application of machinery became general, the working of coal mines passed from the hands of the rule-of-thumb miner to the trained engineer, and this became absolutely necessary in modern collieries, raising, say 3000 tons a day, with hundreds of mechanical horse-power employed for hauling and raising coal, pumping water and ventilation, miles of railway above and below ground, and an extensive establishment of workshops on the surface for construction and repairs. It may, indeed, be said that in carrying out the necessary works for the exploitation of a large colliery, the engineer requires more varied knowledge than in any other branch of the profession, and it has been considered by the author that a retrospective glance at the development of this great industry might be of some interest and value to the Members of the Society.

DISCUSSION.

The PRESIDENT said they were all very much indebted to Mr. Nelson Boyd for the interesting paper he had read. It was full of historical information, put in a very succinct manner. In inviting a discussion he moved a vote of thanks to the author for his admirable paper.

The vote of thanks was passed by acclamation.

Mr. S. H. COX said it had occurred to him during the reading of the paper that the inhabitants of some of the less favoured parts of the world had really been going through the middle ages again during the past few years. For instance, in Australia and New Zealand, in which latter place he had had the pleasure of partially introducing the inspection of mines, he had seen

nearly all the old-fashioned forms of mining at work, even down to ventilating the mine with a simple basket grate put at the bottom of an upcast shaft. In nearly every new district in which coal was worked near the outcrop, the old systems of mining were adopted. The pillar and stall system of working was used, the bords being taken as large as they could be, and the pillars left as small as possible. It seemed very likely that in the early collieries the actual conditions of the workings must have governed the size of the pillars, since, when similar conditions were reproduced now, the workings generally assumed similar characteristics. The workings near the outcrop lent themselves to the large bords and small pillars, whereas in the deep workings, where greater care had to be taken that the mine was not lost entirely, a change in the system of working had to be made. Mr. Boyd appeared rather to pass over the systems of mechanical coal mining as a thing which had been a distinct failure all through. He (Mr. Cox) thought that at any rate the Stanley heading machine was working satisfactorily in a number of cases. Again, there were several classes of machines which were used for undercutting the coal, and which were certainly doing very good work in some districts. Amongst these he might mention the Gillott and Copley machine, which was one of the best he had seen. He had seen it doing very satisfactory work in the Wharncliffe Silkstone Colliery, near Barnsley, and also in the Lidgett mine in the same neighbourhood. In both those cases the machines were working very well indeed with compressed air. Mr. George B. Walker read a paper on the present subject before the Federated Institute of Mining Engineers in 1890, and in looking over the paper he (Mr. Cox) found that the author stated that whereas in a 3 feet seam, working by hand cost from 1*s.* 6*d.* to 1*s.* 10*d.*, the machine work cost only from 1*s.* 3*d.* to 1*s.* 6·7*d.* In a 2 feet 6 inch seam the difference was from 1*s.* 10*d.* to 2*s.* 2*d.* for hand working, and 1*s.* 6·3*d.* to 1*s.* 10·6*d.* for machine work. In a 2 feet seam it was from 2*s.* 5*d.* to 2*s.* 10*d.* by hand, and 1*s.* 11*d.* to 2*s.* 1*d.* by machine. In the 1 foot 6 inch seam the difference was still more marked, being from 3*s.* 2*d.* to 3*s.* 10*d.* by hand, and 2*s.* 5*d.* to 2*s.* 11*d.* by machine cutting. That was not taking into consideration the improved character of the coal which was got by the machine over that got by hand. With machines the undercutting did not require more than from four to five inches at the outside, but working with a pick, holing at any depth would necessarily be more than that, and consequently the coal came out in a much better condition when the machine was used than when it was got by hand. He mentioned these points because it had been rather the fashion to condemn machine

mining generally. It might be that the machines had not had the fair trial which they deserved. He hoped some of the electrical engineers present would give the meeting some information as to electric coal cutters. He understood that such machines were being largely used in America, and that in certain districts they were replacing hand mining to a very great extent. Mr. Boyd stated in his paper that we did not derive more than 5 per cent. of the absolute calorific value of the coal which we burned in all appliances, from the steam engine to the household fire. Was that really the case? It seemed to him (the speaker) to be a very remarkable thing if it was absolutely true. It also seemed to him that, if it was true, the difference between two fuels like coal and lignite for steam production must be very slight indeed. If the effective value was reduced to 5 per cent. in each case the difference must be exceedingly small.

Mr. Boverton Redwood said he always studied with a great deal of profit such of Mr. Boyd's writings as came under his notice. The present paper was in no sense an exception to the rule. He was very glad that Mr. Boyd had taken the present opportunity of calling attention to the possible application of petroleum as a source of illumination, and as liquid fuel as an adjunct to our coal supplies. The author had made a very comprehensive statement to the effect that capitalists required to be educated in respect to the advantage of employing liquid fuel, and of using petroleum as a source of gas. He (Mr. Redwood), presumed the author meant that there were two classes of capitalists who required educating in reference to the subject. In the first place, there were the capitalists who ought to be led to realise that a profit might be made by developing existing sources of supply for use as fuel and in the manufacture of gas. Then there was another class of capitalists who were users of steam, and who needed to be educated to understand that great advantages might result from the substitution of petroleum for coal. He believed that it was mainly the former class of capitalists who should desire further instruction. In Russia, steamships had long been driven on the Caspian Sea with liquid fuel, to the entire exclusion of any other fuel; and locomotives had for years been fired by liquid fuel on the Grazi-Tsaritsin Railway, under the management of Mr. Urquhart. Liquid fuel was also employed on the Trans-Caucasian Railway. Again, in some of the principal cities in the United States coal-gas had been almost entirely replaced by carburetted water gas. An intelligent section of the community fully realised the advantages which might be gained from the use of petroleum as a fuel and as a source of illuminating

gas. There was, however, a difficulty in securing an adequate supply of the material, and it was that difficulty, rather than ignorance of its industrial value, which, in his opinion, stood mainly in the way of the development of the use of petroleum. The great users of fuel were in doubt as to whether they could rely upon the supply of petroleum. There seemed to be a strange hesitation in taking the initiative in placing supplies of suitable material on the markets of this country. No doubt there must be a considerable expenditure of capital before that could be effectively done, and the already large number of tank steamships afloat would need to be augmented. The petroleum which had been already employed was principally that which must be regarded as a by-product in the manufacture of certain commercial products, notably the oil which was used in lamps. But it was well known that there was a large number of undeveloped, but available sources of supply of petroleum exceedingly well adapted for use as fuel. In many cases the supplies lay close to the sea-coast, and therefore would admit of convenient shipment. There was therefore every reason to believe that they could be opened up with profitable results at the present time. It was not often that they were favoured with the views of a gentleman who was at once an authority upon coal and an authority upon petroleum, and for that reason he thought that the Society owed its thanks to Mr. Nelson Boyd for the exceedingly interesting and valuable communication which he had presented.

Mr. Price Williams said that having had the honour of working out for the Royal Commissioners the calculations with reference to the duration of our coal supply to which the author of the paper referred, he could, perhaps, throw some light upon the reasons for the rather vague way—as the author called it—in which the estimates were put forth. The estimate of 360 years was arrived at by taking into consideration the decreasing rate of increase of the population and the rate of increase in the output of coal. The report of the Commission was undoubtedly the most valuable paper which we had with regard to the quantum of what he might call the life-blood of this country; our coal resources constituted in reality the backbone and power of the country; the Commissioners' Report gave a most complete and exhaustive statement of the quantity of coal which still remained. He believed five or six years were devoted to gathering information; and in July 1871, a few weeks prior to the completion of their Report, they called upon him to "condense" the results of their five or six years investigations. The time for the work was very limited, and he at first naturally shrank from undertaking the task, but he ulti-

mately agreed to do the best he could within the very limited time allowed him. He wished to lay stress upon that point, because undoubtedly the conclusions which he drew in 1871, and to which the Commissioners in their report referred, were to a great extent modified by the more recent investigations he had made on the subject. It was obvious that if they merely took into account the total annual output of the kingdom, including South Wales, where they were working out the famous 4 feet steam coal seam, as it was called, at the rate of 7 acres a day, and on the other hand, the coal districts in the Black Country where the output had been decreasing for years, the average rate of increase, which was the only thing which he could furnish to the Commissioners, could not, as he expected, be altogether reliable.

Although at the time of these earlier investigations he differed from the late Prof. Jevons in his view that the coal supply would not last more than about a hundred years, he was bound to say that the result of his twenty years' subsequent experience undoubtedly tended to confirm the view which Prof. Jevons arrived at, and that from one hundred to one hundred and twenty-five years would be the limit of the duration of the supply. Prof. Arnold Lupton, who had had a large experience, was disposed to hope that under the Permian there were still large and undiscovered sources of coal. He (Mr. Price Williams) hoped that might prove to be the case, but, be that as it might, such coal would be at a very great depth, and mining engineers well knew that when coal was worked at a greater depth than 4000 feet, the conditions would be such as to render it almost impossible to be worked at all, and if even it were otherwise, the price would be so enormously increased as to render it unsaleable. But whether the exhaustion of our coal supplies occurred at the end of 100 years, or of 200 years, either period constituted but a brief interval in the history of a great country like ours. The country was now realising, in the present strike, to some slight extent what must inevitably happen not merely for a few weeks or months, but for all time, when our coal supplies were exhausted. He was not an alarmist, but he maintained that the prospect of the exhaustion of the coal fields was indeed a terrible one to look forward to. The author of the paper incidentally referred to other sources of power, but coal, or as Stephenson called it, "bottled sunshine," was, after all, the cheapest form of power in the world, and when our coal went the population would and must follow it to other countries, like New South Wales, where there were almost inexhaustible supplies of this precious material.

He was glad to know that there were also enormous supplies

in New Zealand, but of what avail would they be to this country?

He believed that the evil day might still be postponed for a considerable period by preventing the enormous waste in working the coal. For instance, the Commissioners in their Report draw attention to the fact that one-third of the coal was left underground, as pillar, and in the shape of small coal in the "gobs." That was a scandal, and he thought the time had arrived when legislation should be obtained to prevent that shameful waste. He had only recently returned from a celebrated colliery in South Wales, where he asked the manager what he did with the small coal. The answer was, in a whisper, "We leave it in the gobs." He agreed with the observations which had been made with regard to the improvement in coal-cutting appliances. He made his first acquaintance with colliery working in South Wales as far back as 1848. Since then enormous strides had been made, but as regarded underground working the collieries in this country were a century behind those of New South Wales in point of cleanliness. He believed that they must look to electrical appliances for safety and for economising the cost of coal cutting and underground haulage. We had one pleasant reflection in connection with the question of our coal supplies, and that was that, thanks to the discovery of the Bessemer process, to the more general application of machinery in coal cutting a very marked economy had already resulted. The saving of coal effected by the Bessemer process alone, by doing away with the puddling process, was enormous, as shown by the very interesting statistics recently published in the Proceedings of the Iron and Steel Institute.

The author had referred to his (Mr. Price Williams's) estimate of $2\frac{1}{2}$ per cent. per annum in relation to the future rate of increase of the coal output. He presumed the author was referring to the paper which he (Mr. Williams) read a short time ago at the Statistical Society. The actual rate of increase —during the period antecedent to the Report of the Royal Commission—was much greater, viz. 2·93, or nearly 3 per cent. He was pleased to find that since he read his paper on the coal question in 1887, the reduced rate of $2\frac{1}{2}$ per cent. had been attained. That difference represented an economy of about a million tons in five years. The difference was a small one, but it showed that the rate of decrease was, as pointed out in the Commissioners' Report, a geometrical rate. He hoped that the $2\frac{1}{2}$ rate would still further diminish, but even this would only put off the evil day a little farther. It was interesting to observe that the highest tonnage reached was in 1890, when the output was nearly $181\frac{1}{3}$ million tons. This year it

was only 181 millions. Since he read his last paper on the coal question, namely, nearly five years ago, there had been considerable fluctuations, and the rate of increase had only amounted to about $2\frac{1}{3}$ per cent. per annum instead of $2\frac{1}{2}$ per cent. The low rate of $2\frac{1}{2}$ per cent., however, meant the doubling of the output in every 28 years, while in a period of 100 years the output would increase nearly twelvefold. In other words, the output at the end of a century from the present time would be nearly 2200 millions.

Mr. Perry F. Nursey said there was no doubt a great deal of "sweet reasonableness" in what coal alarmists had to tell them, and it would be well to prepare for such contingencies as they foreshadowed; but he thought that, on the other hand, they ought to take a little note of the contingency of fresh sources of supply. In his inaugural address as President of the Society in 1886, he touched upon the question of coal exhaustion. At that time Jevons, Playfair, Dewar and one or two others, had brought the coal bogey into very considerable prominence, and he (Mr. Nursey) then combated their theories in a practical way, so far as he could, and stated that in 1876 he had visited the South Yorkshire coal fields and found that over a hundred new collieries had been started in that district within a comparatively short time of his visit, and he gave all their locations. Four seams had just been intersected at a depth of less than 500 yards, and extending over an area of 15,000 acres. New coal districts had also been opened in South Wales just before the delivery of his inaugural address, and to which he had also referred. Since that time coal fields had been opened out in other countries and in the British colonies. He did not think that Englishmen would find themselves in quite the coalless condition which had been predicted, even in 200 or 300 years' time. They knew, however, that exhaustion must come, sooner or later in the course of time, at whatever distance that period might be, and therefore the question of providing against that day was a very proper one for consideration.

The great remedy appeared to be petroleum. Prof. Redwood had spoken plainly on the subject, and he had expanded what he (Mr. Nursey) had stated at the last meeting of the Society, namely, that the difficulty with petroleum was to obtain supplies forward. Pinkus had started the question of petroleum furnaces in 1830, when he used petroleum vapour and air. Then they had had Richardson, Bridges Adams, Wise, Field and Aydon, Crow, Dorsett, Admiral Selwyn and Tarbutt in England, Verstraët in France and Urquhart in Russia. He had inspected the working of all the English apparatus, and he was satisfied that their methods of using

liquid fuel would work economically—some, of course, better than others—if they could only ensure a supply of oil at a steady price; but as soon as any of the inventions were started in use in England up went the price of petroleum, which was before almost a drug on the market. The matter just came to this, as Prof. Redwood had stated, that capitalists should combine to organise a system of petroleum supply. There was plenty of petroleum to be had, and there were plenty of means of getting it to this country, and there were plenty of uses for it and plenty of places in which to use it. What was really wanted was enterprise and capital.

In conserving our present supply of coal, he might observe that millions of tons of slack and smudge were lying at our collieries as waste. A considerable amount of it was at present used in making coal bricks, or "briquettes," as they were called. That manufacture had been going on for years past. In a paper which he read before the Society about thirty years ago he went fully into the subject, and since that time improvements had been made in briquette machinery, and a great amount of coal slack had been used up. He had recently inspected the working of an apparatus for making coal bricks, in which a mineral and a vegetable substance in combination were used for binding the smudge, instead of pitch or other bituminous substance. The two substances were mixed with the slack, and live steam was forced into the mould. The material was then moulded under very high hydraulic pressure, and excellent coal bricks were produced. Their manufacture had been started, and he believed that they would soon be placed on the market.

The author had appropriately touched upon the subject of peat as a fuel. The difficulty of getting rid of the contained water, however, was not the only one nor the worst one with regard to peat. He formerly gave some attention to the subject, and had seen several processes for preparing peat for fuel, and the general result of the machines employed had been that they had broken down in one way or other, in consequence of the difficulty of getting rid of the tough fibrous roots and stalks present in the peat. These roots and stalks were the *bête noire* of the peat process. There was no doubt that if they could be digested or otherwise treated cheaply, the great bulk of the peat could be utilised, and would make very good fuel. Peat cut from the bog and simply hand dried made excellent fuel. The great difficulty in this country was to get it in a denser and more marketable form. A sample of prepared peat exhibited on the table had attracted his attention. He presumed that there was a history attached to it. He would like to know if it had been produced commercially.

Mr. Boyd said the sample of peat referred to had been produced by the Blunden machine, which, so far as he knew, was the best that had been invented for the preparation of peat. A hole was made through the lengths of the material, in order that it might dry more quickly. That form of peat dried very much sooner and more perfectly than the peat produced by any other machine which he had previously seen. It was a very good conglomerated sort of condensed peat, and was simply hand dried or sun dried, he believed.

Mr. W. Worby Beaumont said he did not wish to dispute the author's statement that the average efficiency obtained from all the coal that was burnt was about 5 per cent., but while from a purely thermodynamic point of view that statement might be true, it must be remembered that some steam boilers gave an efficiency of over 80 per cent., and some engines gave over 80 per cent. of the possible useful effect from steam and 10 per cent. efficiency from a heat-engine point of view. Perhaps the author had included the many thousands of kitchen ranges, which possibly gave an efficiency of from 2 to 4 per cent. Those low figures might bring down the average to the author's 5 per cent. That suggested the question whether it should be below the dignity of the engineer to take up the subject of the construction of kitchen ranges. On one occasion he took the trouble to see how much coal was required to heat an oven sufficiently to cook about 10 lb. of meat, which contained, perhaps, 6 lb. of water. The oven was maintained at a temperature of about 400° for about $2\frac{1}{2}$ hours. Some of the water was evaporated from the joint of meat and other things heated and cooked. As nearly as could be estimated, the heat units theoretically required about 16,700 units, so that about $1\frac{1}{2}$ lb. of coal ought to have been sufficient to supply all the heat, but 27 lb. were used. He almost thought that the time had come when some engineer should devote his attention to an endeavour to save a large part of the difference between $1\frac{1}{2}$ lb. and 27 lb. He was quite sure that a great many people would be glad at the present time to effect such a saving. Generally the waste by kitchen ranges was greater than that mentioned, for the consumption of 27 lb. was with the most careful stoking, for the purpose of experiment, the usual quantity used being at least 35 lb. when in ordinary hands. Taking the 27 lb.—the best result—the heat efficiency would be 5·5, and in less careful hands that fell to 3 per cent., and there were probably many thousands of kitchen ranges in middle class houses where it fell as low as 2 per cent. and even less.

Personally he did not take a strong interest in coal mining. Perhaps that might be accounted for by an incident which the

author mentioned in the interesting book which he had written on 'Coalpits and Pitmen.' It was that a certain ancestor of his (Mr. Beaumont's) went up to the north and took to coal mining, and, having spent 30,000*l.* and lost it, returned to the south "on his light horse." Perhaps that explained why coal mining did not run in his (the speaker's) blood.

With regard to the exhaustion of coal fields, he thought the importance of that matter was sometimes overrated, for as soon as the supply of coal fell off attention was directed to obtaining supplies of fuel from other directions, and when pressure was brought to bear we might become more economical in the use of coal. Extravagance in use would be checked by rise in cost, economic methods would replace our methods, which were universally wasteful, except with the better class of steam engines. Apparatus would be devised for burning inferior coal, and means would be found for obtaining by wind and water power and electricity a good deal of what we now get from coal. Hence, one way and another, the gradual depletion of the coal beds, even supposing it was taking place, would not concern us in the way usually taken into consideration.

Mr. Reginald Bolton said it was now about 660 years from the time of finding the first coal at Newcastle, and that period included a considerable space of time during which coal was very little used. The first manufacturers who used coal were dyers, and these were followed by brewers. The author might have done himself the justice to refer the Members for further information upon this interesting question to his excellent work upon the subject. That was a work which he (Mr. Bolton) had read with considerable interest, and from which he had learned a great deal. At the present period of strikes all were interested in the coal question on account of its effect on their pockets. It might be, perhaps, not altogether inappropriate to mention that in searching into the question of strikes he had met with what he believed to be the very first use of the word "strike." It was dated the 9th May, 1768. Previous to that time, what was now called a "strike" was called a "stick." The latter seemed, also, to be a very appropriate term.

The application of electricity for the purposes of coal mining was a very important matter, even from the point of view of the coal alarmists. He had at work some electrical machinery which was now being largely employed, and in which great interest was being taken by practical miners. The difficulty in the use of compressed air had always been in its conveyance and distribution, and although a very efficient compressed-air undercutting pick had been in use in the United States for some

years, he did not think the appliance would in any way compare with electrical coal cutters, which were being introduced into the Scotch mines in some numbers. He had heard of a disc machine of the Gillet and Copley type already referred to. That took a 10-horse motor, the cutter revolving at a speed of 20 revolutions per minute. The type which seemed to find most general approbation was that operating a revolving cutter bar. It had been improved lately in several ways, more particularly with regard to the method of holding the outer end of the bar, which was always a weak point. These bar cutters were run at a comparatively high speed, namely, 250 revolutions a minute. A machine of that character with a bar which undercut from 3 feet to 5 feet deep, was supplied with a 14-horse power electro-motor, running at about 600 revolutions a minute. A great deal was also being done with regard to electric pumping.

Some pumping plant to deliver 200 gallons per minute against a head of 650 feet was being put down at the Newbattle collieries at Dalkeith. It would be driven by two motors of 60 horse-power each, the current being generated at bank. Ordinary high-pressure engines were employed for generating the current. At the New Mains Colliery pumping plant was being put down for the delivery of 200 gallons a minute against a head of 130 feet. Those pumps were driven by a 13 horse-power electro-motor, with current generated at bank. A very efficient plant had been at work for some time at the Seaton Colliery. This delivered 250 gallons a minute through an 8-inch pipe. The current was conveyed 2700 yards, being generated also at bank. Many of these plants had also electric lighting installations in connection with them. All the installations appeared to give satisfaction. He was aware of more than one case in which electric plants were employed with success in lighting the larger galleries below, but it still remained for engineers to make an efficient electric miner's lamp.

Mr. G. A. Goodwin referred to the discovery of coal at Dover by the South Eastern Railway Company as an instance of its being found in quarters in which its existence had not even been suspected, and pointed out that this unknown factor tended to discount the unfavourable views that were sometimes entertained as to the near future working out of our coal fields. Speaking as a mechanical engineer, he regretted that the paper had not given more details of the mechanical appliances used in coal mining. With regard to collieries which had not been worked successfully, he would like to know in what respects the machinery used therein had failed, so that engineers might have an opportunity of devoting their attention to the subject with a

view to making improvements? The author mentioned that electric lamps had not proved a success in collieries. From an electrician's point of view he would like to know whether the failure was due to weight or to want of durability, or to what other cause? In referring to various kinds of fans, the author had omitted a very important one, namely, the Walker fan. It was very efficient, worked in conjunction with a shutter having a V-shaped outlet.

Mr. R. NELSON BOYD: That is the Guibal fan.

Mr. GOODWIN, continuing, said that was so, but combined with the shutter was known as the Walker. The author made no mention of the use of compressed air engines for haulage underground. They were largely used in the North. As the paper was, to a large extent, a historical one, he would mention a breaking down machine which was made about 1869 by Mr. Chubb, at the works where he (Mr. Goodwin) was apprenticed. It was constructed out of a solid circular steel bar, with a part of the circular portion sliced off. Small rams were recessed into it all along, and a strong cast steel cap fitted over all so as to distribute the pressure and prevent one moving out faster than the others. A hole was bored in the coal approximately fitting the apparatus, which was inserted therein, with the rams pointing in the direction of the under-cut. Water was then pumped in all the ram cylinders by means of a hand pump by a connecting bored hole and pipe. The rams were forced out, and broke the coal away in the particular direction wanted without breaking it up into small pieces, and without danger of explosion. With regard to the use of fine coal he had had some experience in making briquettes of it, and he was inclined to think that the colliery owners who allowed it to be wasted did so through ignorance rather than through indifference, because there was an actual market for the briquettes, and he knew some collieries where plant had been put down for making briquettes with very satisfactory commercial results. The fine coal was simply mixed with a little tar and lime in a pug-mill, heated by steam and then compressed into moulds. Some of the State railways in Belgium and France used with economy nothing else than these briquettes. There was no reason why they should not be so used in this country, but he believed they required a somewhat larger fire-box than was usual on our locomotives. The author had not referred to overwinding gear. That was a very important and interesting subject. He, Mr. Goodwin, had had occasion to make a report upon a most efficient apparatus of that kind, in which the overwinding was prevented by the following simple arrangement:—When the cage came to bank it struck a tappet, which had simply to

withdraw a wedge, and so was not subject to much of a strain. The releasing of the wedge put a piston valve in action, which, when opened, allowed the steam from both ends of the cylinders to exhaust to the atmosphere; at the same time it shut the main throttle valve and admitted steam to the steam brake. The main drum of the engine being gripped by a powerful brake encircling the whole circumference, and all the internal power in the engine being immediately relieved, the whole apparatus was brought to a standstill without putting any strain on the drum. All that it had to do, and the strain passed through the arms was to bring the moving parts of the engine to rest, the weight of the cage being taken by the periphery of the drum. He had tested the apparatus, and he found that the cage, although travelling at the rate of 20 feet a second, did not rise more than 3 feet 6 inches from the ground, or 1 foot 3 inches after striking the tappet. The overwinding gear did not, however, provide against the cage striking the bottom of the shaft; but the danger due to that was not so serious as was sometimes supposed. Striking the ground at a velocity of even 30 feet a second was only equivalent to a vertical fall of 14 feet, and he thought that they would all agree that that would not be a dangerous height.

Mr. J. W. Wilson, Jun., reminded the Society of a point which would throw light upon the question of the deficiency of the supply of petroleum. Last year the Members paid a visit to the Great Eastern locomotive works, and during their inspection Mr. Holden showed them the oil burning locomotive "Petrolea." Mr. Holden was asked why he did not make more of the same type, and he replied that until he was sure of a better supply of oil it would be out of the question to increase their number. It was very important that engineers should do their best to bring about in every possible way economy in the use of coal. If any good at all came out of the present coal strike, it would be possibly in the way of directing attention towards some of those points of economy which were so important in the present connection.

The President said that communications upon the subject of the paper had been received from Mr. William Topley and Mr. A. Strahan of the Royal Geological Survey, which would be published in the 'Transactions.'

Mr. Nelsod Boyd, in reply, said Mr. Cox had stated that the undercutting of coal could be done much better by machinery than by hand labour. That, however, was a question which had not been solved in England. Experience in this country had shown that more coal could be cut by machinery than by hand, but the great cost had swamped the advantage.

The difficulty was not so great in a face which was not more than 300 or 400 yards from the bottom of the pit; but the carrying of power to great distances underground involved very considerable difficulty and cost, and therefore in such positions mechanical undercutting had not been successful. Another point which must be taken into consideration was the character of the seam which had to be cut. Where the seams lay fairly evenly, as they did in America, the mechanical undercutter could be used with advantage; but in the Midlands and in Yorkshire it would be exceedingly difficult to apply the machine, and in those places it had been neither economical nor successful.

He observed that Mr. Price Williams still held to the statement which he published some years ago, namely, that our coal fields would be exhausted somewhere within the next hundred years. Mr. Price Williams was an authority upon that subject. He (Mr. Boyd) disagreed with regard to the $2\frac{1}{2}$ per cent. rate of increase of production per annum. He believed that that figure would be very much altered within the next few years. Petroleum was being very largely used in London; coal briquettes were also being used as fuel in houses; and even the improvements which would be made in the steam engine itself would lead to a very large economy in coal. The great majority of steam engines at the present time did not yield more than 12 or 16 per cent. of efficiency at most, and engineers were beginning to find out that the steam engine was a faulty machine which required improving. He questioned whether at present much more than 5 per cent. of the value was obtained out of the 180 millions of tons of coals annually consumed.

With regard to the use of petroleum, to which Mr. Nursey had referred, we had not much improved either in supply or price during the last twenty years as far as liquid fuel was concerned. The price would fall as soon as an adequate supply was obtained. Hitherto all the petroleum which had been obtained had been used for the purpose of producing kerosene or lighting oil, and it was only when the world had been supplied with as much lighting oil as it required that petroleum would become available for fuel. We were not developing the resources of petroleum which existed in Canada. The material was lying there untouched, waiting for some one to overcome the difficulties of a northern climate, and make a pipe line and bring the petroleum over at $1\frac{1}{2}d.$ or $2d.$ a gallon. There were other sources in Venezuela and Mexico, in which countries there were immense deposits lying untouched and waiting until capital was educated up to the advantages which petroleum could bring in the shape of dividends.

He regretted that Mr. Beaumont should complain of his ancestor's proceedings in the north of England. That ancestor did the country a great deal of good, and Mr. Beaumont ought to be proud of him. He introduced wagons and he was perhaps the father of railways. It was true that Beaumont was not mentioned in connection with railways, but it was said that he introduced a new efficient wagon, which possibly might have run on rails; whence he might be considered the father of railways. He (Mr. Boyd) should have been proud of such an ancestor, and for ever love coal. It was written of him that he left Newcastle with a light horse, and left 30,000*l.* behind for the benefit of those who came after him.

As to the words "strike" and "stick," the latter was the old Scotch word, and "strike" was the word which stood for the opposition of colliers to those who wished to reduce their wages below a certain point. They "struck" in England, and they "stuck" in Scotland. Mr. Goodwin had asked what were the objections to the use of the electric light underground. One objection was the weight of the lamp. Another was that if a lamp was charged for a certain number of hours the miner would be left in the dark if he exceeded the time. The Walker fan was an appliance which he (Mr. Boyd) did not know. He knew the Guibal fan, which had been somewhat altered by Walker, and he presumed that that was the fan to which Mr. Goodwin alluded. Walker altered the construction of the shield to some extent, and he certainly improved the fan, but the fan was really Guibal's. It was introduced in the year 1862, and was an exceedingly good fan, and was very much used, although modern engineers preferred a quick running fan, namely, the Schiele and the Waddle.

Chubb's coal-breaker he had known for many years. It was tried in the midland counties, and in the north of England, but it did not suit. Mr. Sam Bidder, the nephew of George Parker Bidder, invented a machine which was tried in the midland counties, but it cost so much to force air down to work it, that it did not pay to use it. It was a very pretty machine, but in the coal mining district they wanted practical results. With regard to briquettes, he knew a man who invented a way of making briquettes out of stale potatoes. That was at the time when there was a bad crop of potatoes in Ireland and the potatoes could be obtained cheaply. Then there came a good year, and the potatoes were dear, and the inventor had to stop his factory. He (Mr. Boyd) had seen briquettes from Swansea burnt in Chili. They were made from dry coal, thoroughly compressed, and were very hard and consistent. They cost about 2*l.* 10*s.* a ton in Chili.

As to overwinding gear, he had not mentioned it, for he was old-fashioned enough to think that it was the business of the colliery engineer to examine the ropes every day, and to replace them if there was the slightest sign of a flaw. Another thing to be considered was that accidents in the shafts were very few. Appliances for preventing accidents through the breaking of ropes were things which people on the surface could invent by the score. He believed that more than twenty such inventions would be found in the Patent Office, but when a rope broke the accident happened all the same. He agreed with Mr. Wilson as to the petroleum supply. He hoped that petroleum would be used in the future, not only for gas-making but for locomotives and for other purposes.

The following are the communications referred to by the President:—

Mr. W. Topley, of the Geological Survey, writes:—In view of the importance of detailed surveys of the coal fields and possible new developments, it may be of interest to state the present position of the question as regards the work of the Geological Survey. The coal fields of central and southern England and of Wales were surveyed many years ago on the 1-inch scale. Those of the north of England, Scotland and Ireland were surveyed on the 6-inch scale. The coal fields of Yorkshire, Lancashire, Northumberland and Durham are published on the 6-inch scale; those of Whitehaven and Flintshire are only published on the 1-inch scale, but MS. coloured copies of the 6-inch maps can be supplied if required. In consequence of representations made in Parliament, directions were given in 1891 for the re-survey on the 6-inch scale of the South Wales coal field. During the present year application has been made for the re-survey on the 6-inch scale of the North Staffordshire coal field. This also has been acceded to by the Science and Art Department, and the work will be commenced early in next year. It is impossible with the small staff now employed by the Geological Survey, to undertake more work of this kind at present; but such re-survey is greatly needed in all the southern coal fields, and it could be advantageously applied also to those parts of the north of England surveyed many years back on the 6-inch scale.

The concealed area of the Leicestershire coal field much requires systematic investigation. Numerous trials have of late years been made; some have been successful in striking the coal, but others have touched the older rocks, the coal

there being absent. The Nottinghamshire coal field has recently been greatly developed in its eastern border, under the newer rocks. This area was included as coal-bearing by the Royal Coal Commission. On the east of the South Staffordshire coal field a large space was omitted from calculation. The famous sinking at Sandwell Park showed that this was a mistake, and there can be little doubt that coal at workable depths extends far under the Permian and new red sandstone to the east, probably joining on the proved coal field of Warwickshire.

There are reasons for regarding it as highly probable that coal exists south of the Mendip Hills. In the south-east of England long discussions as to the probability of the existence of coal have given place to certainty by the discovery of coal at Dover, which is a westerly extension of the important coal fields of North-west France. It is exceedingly likely that coal exists under the tertiary and cretaceous rocks in the south-east of England and in other places; probably as detached basins along a general east and west line.

All such areas have to be added to those reported upon by the Royal Commission, and therefore estimates of our coal resources have now to be increased by a large, but, at present, all inadequate amount.

Mr. A. Strahan, of the Geological Survey, contributed the following notes on the results of the re-survey of the South Wales coal field, so far as relate to the area already mapped in the south-east part of the district, embraced within Sheet 249 (New Series) of the Ordnance Survey Map.

The coal measures are distinguished by colouring into (1) an Upper Series, based by the Mynyddislwyn Vein (household coal); (2) the Pennant Rock, in which a few seams of household coal occur, viz. the Brithdir (or No. 2 Rhondda), and the Rock Veins; (3) a Lower Series, including all the steam coals.

The Mynyddislwyn Vein is still worked, but has been exhausted over much of the area. The Brithdir Vein is developed only in the northern part of the area, where it has been and still is extensively worked. The Rock Veins are developed along the south crop.

The steam coals constitute the principal source of supply for the future. After plunging at a steep angle beneath the Pennant Grit along the south crop, they do not appear again at the surface till the north margin of the coal field is reached. In order, therefore, to calculate their position in the central parts of the coal field, it was necessary to map out the seams in or above the Pennant. For this purpose the Mynyddislwyn

and Brithdir Veins proved most useful. The Mynyddislwyn Vein occupies two distinct basins, one at Caerphilly, the other about 6 miles further north, the two being separated by a broad anticline of Pennant Grit. In neither basin have the steam coals yet been touched, but their depth below the Mynyddislwyn Vein is known within narrow limits, and the faulting and structure has been minutely worked out in each case.

The broad anticline has already been taken advantage of for the sinking of deep shafts, and the steam coals are being energetically worked at depths of from 500 to 600 yards. To the north of the northern Mynyddislwyn basin the Brithdir Vein has been and still is largely worked, the workings in fact extending under those in the Mynyddislwyn Vein. In this belt of ground the depth to the steam coals is calculable by reference to the Brithdir Vein. The deepest pit hitherto sunk on the north side of the Mynyddislwyn basin is 760 yards.

December 4th, 1893.

WILLIAM A. McINTOSH VALON, PRESIDENT, IN THE CHAIR.

SOME PRACTICAL EXAMPLES OF BLASTING.

BY PERRY F. NURSEY, PAST PRESIDENT.

THERE is, perhaps, no more appropriate illustration of the work of the engineer in directing the forces of nature than that afforded by the use of explosive compounds. A high explosive represents a special form of force. It is a maximum of power compressed within a minimum of space, its resistless energy being ready for liberation at a moment's notice. This stored-up force, which is in a high state of tension, is simply an ingenious assemblage and intimate admixture of all the elements which it is necessary should be united in combustion, including oxygen, so that in action they are independent of the atmosphere and can be exploded under water. It is, moreover, force in a portable and handy form, and which, under perfect control, is utilised in the removal of gigantic obstructions and for cognate purposes of minor character. Being capable of development and utilisation at any given moment, this force is of the greatest service in many engineering as well as naval and military operations, enabling large masses of rock or structural obstructions to be removed in a short time and at a comparatively small cost. Were it not for this concentration of force as developed in modern high explosives, many mining operations would have had to be carried on at a ruinous cost, or suspended altogether; for in some cases ground is met with which ordinary gunpowder will not touch, the charge blowing out as from a gun.

In order to realise what the liberation of this condensed energy means, it may be interesting to briefly consider, theoretically, the circumstances attendant upon the explosion of gunpowder. According to Abel, this compound yields upon explosion 43 per cent. by weight of permanent gases, and 57 per cent. of matter which is solid at ordinary temperatures, but part of which may exist as vapour when the powder is exploded

under pressure. At 0° C. and ordinary barometric pressure, the permanent gases generated by gunpowder occupy about 280 times the volume of the original powder. As, however, the temperature of the explosion of gunpowder is about 2200° C., or nearly 4000° Fahr., these gases exert a tension, when developed in a confined space, which amounts to about 6400 atmospheres, or about 42 tons on the square inch if the powder entirely fills the space in which it is exploded. The total theoretic work which gunpowder is capable of performing in expanding indefinitely is about 486 foot-tons per pound of powder.

It would be interesting to know if there are, as yet, any sufficiently authentic data upon which to base a statement similar to the foregoing with regard to dynamite or other high explosives. As, however, dynamite is a mixture of nitro-glycerine with an inert absorbent—kieselguhr—any statement must relate only to the nitro-glycerine contained in the dynamite, and not to the compound itself. As regards nitro-glycerine, Nobel estimates that one volume disengages 1298 volumes of gases of 100° C., at a barometric pressure of 760 mm., consisting of 554 water vapour, 469 carbonic acid, 236 nitrogen and 39 oxygen. List estimates the bulk of the liberated gases at 1504·9 volumes. Nitro-glycerine, therefore, evolves nearly six times as much gas as gunpowder computed for a temperature of 100° C. A far higher degree of heat, however, is produced by the instantaneous combustion of nitro-glycerine, which, according to Nobel, expands the bulk of the freed gases to eight times the original 1298 volumes, whilst the gases of gunpowder would not be trebled at the temperature just following explosion. The explosive force of nitro-glycerine, therefore, stands in relation to that of gunpowder as 13 to 1 according to volume. The principle here involved appears to the author to be important as having a bearing on the method of proving rifles, sporting guns and artillery, in which modifications of nitro-compounds, otherwise known as smokeless powders, are used as the propelling agents.

In previous papers upon the subject of explosive compounds which the author has had the honour of reading before the Society*, he has mainly confined himself to their history, their characteristics and their practical application. In this latter respect he has given examples of his own personal experiences with some of them. Those examples, however, although chiefly carried out under actual working conditions alike as regards industrial, naval and military operations, can, from their restricted nature, be regarded as but little more than experiments.

* Vide 'Transactions' for 1869, p. 10; 1871, p. 108; and 1889, p. 71.

Upon the present occasion, therefore, he proposes to bring before the Members some examples of blasting as carried out by him in purely practical work. Lest it should be thought egotistical on his part thus to confine himself to his own practice when blasts of far greater magnitude than he has ever undertaken have been carried out by others, the author would observe that in previous communications he has given particulars of all blasting operations of any importance which he has witnessed or of which he has been able to obtain particulars. These include a 3-ton and a 5-ton gunpowder blast respectively at the C.arae and the Furnace quarries on Loch Fyne, which he witnessed in 1879; the Roundown Cliff blast at Dover with 9½ tons of gunpowder in 1843; the 6-ton gunpowder blast at Holyhead, when the harbour was being constructed; the 5½-ton dynamite blast at San Francisco in 1885, and the 150-ton mixed explosives blast in the same year, when the Flood Rock at the entrance to East River, New York, known as Hell Gate, was removed, and which is the heaviest blast on record. In this blast there were employed 240,399 lb. of rackarock, 42,331 lb. of dynamite, and 240 lb. of fulminate of mercury, the latter being in the form of detonators.

Demolition of a Palisade and Bridge at Quenast.

The earliest work of practical structural demolition carried out by the author was in 1872, at the extensive quarries of Quenast, in Belgium. These quarries are situate about 18 miles from Brussels, and occur at intervals over an area of nearly a square mile of country, there being a great number of workings which are connected together by numerous lines of tramway. The stone is a very hard, compact greenstone, which is used throughout a very large district of the country for paving and road making. At these quarries the author was demonstrating the power, safety and economy of the then new explosive compound lithofracteur, as well as the services it was capable of rendering to the mining industry, to military engineering, and to naval operations. The trials on a large scale were directed by the Belgian Government to be made, and the author, in conjunction with Herr Jacob Engels, the inventor of lithofracteur, carried them out before M. Weiler, the Minister of War, M. Kindt, the Minister of the Interior, and a committee of Belgian naval and military officers. Lithofracteur is a nitro-glycerine compound, and constitutes a species of dynamite, than which it is slightly more powerful but slightly slower in action. In mining operations it therefore fissures the rock over a large area instead of smashing it up within a comparatively restricted

space. The experiments included heavy blasting in the quarries, the demolition of a military palisade, torpedo work, and submarine mining operations. As the removal of the stockade was a practical military operation, the structure having been put up by soldiers, it may be here noticed. The palisade, which was erected on the side of a slope, was double, and consisted of a single row of half round timbers at the front, with a double row of similar timbers 8 feet to the rear. Behind the front structure a charge of about 30 lb. of lithofracteur cartridges was quickly lodged, being disposed in a line and covered with earth as a tamping. A capped and fused priming charge was inserted, the fuse lighted, and in a few minutes a tremendous explosion took place. The rear palisade was sent flying in fragments through the air, with a cloud of earth, while the front one was cut off at the ground line and practically disappeared, and a hole 13 feet by 12 feet by 5 feet deep was formed. The earth was loosened to a considerable depth in the cavity, affording facilities for the rapid formation of an entrenchment. Large pieces of timber which had formed the palisade were hurled about 1000 feet from the spot where the structure had stood, while a tree to the rear was uprooted.

Amongst other things which the military authorities desired, if possible, to have exemplified, was the demolition of some such permanent structure as was likely to be met with in warfare. It so happened that a line of tramway on embankment connected with the quarries was being diverted, and at a point where the tramway crossed a roadway there was a one-arch masonry bridge of 20 feet span, 15 feet high and 12 feet deep, which had to come down. It was proposed to demolish the structure forthwith by blasting, and the proposition being readily acceded to, a train of cartridges was laid across the crown of the arch, tamped with earth, and exploded, with the result that the crown was cut through from side to side. Similar trains were laid on the haunches, which had been laid bare, and simultaneously fired, the result being that the bridge was quickly reduced to a mass of ruins. The author does not, of course, consider this demolition was carried out with by any means an economy of explosive, but rather with a too liberal expenditure. But the object was to demonstrate that such a structure could be rapidly and effectually cleared away if it suddenly became necessary so to dispose of it in military operations. This, and the other work done, however, proved so satisfactory to the ministers of war and peace, as well as to their colleagues, that no difficulty was experienced in introducing lithofracteur into Belgium for the various purposes for which high explosives are employed.

Removal of Rocks at Jersey.

In his inaugural address as President of the Society in 1886, the author briefly alluded to a heavy blasting operation which he carried out in 1873, in conjunction with Herr Engels. In order, however, to render the present paper complete, as a record of his own work, he purposes including a notice of that operation in a more detailed form. He will, however, first describe some lighter blasts which he carried out upon the same occasion. These operations were all undertaken in connection with the Jersey Harbour Works, when the late Sir John Coode desired to remove, amongst other obstructions, some portions of the Hermitage Rock, as well as a wall of rock standing out from the main rock in the vicinity of the Hermitage.

The material is very hard and dense syenite, traversed by broad bands of trap rock. In selecting a blasting material the engineer of the works endeavoured to secure one which, while more powerful, should be no less safe than gunpowder. Above all it was necessary that it should be capable of withstanding the action of water for a time. The reason for this was that there were circumstances in which the explosive had to be placed in clefts of the rocks at low water, and allowed to remain there until the tide had risen over it, when it was fired with good effect, the water offering great assistance to the action of the explosive. Lithofracteur was the nitro-compound selected for trial, and it was first employed in the removal piecemeal, by nipping charges, of a large mass of rock standing out to sea in front of the Hermitage Rock. Small charges of lithofracteur were distributed over the rock in bore-holes and crevices, and fired simultaneously by electricity, a frictional machine being used. Large masses of the refractory material were successfully brought down, and the main body so loosened and fissured as to fall an easy prey to the quarrymen who followed up each blast with a vigorous application of crowbars and hammers.

In another instance it was desired to remove a mass of rock attached to the main rock, but partially separated from it by a crevice. In this case a 50 lb. charge of lithofracteur was lodged and secured at the end of the crevice as shown at Fig. 1, and the capped fuse led up the rock. The charge was exploded with 8 feet head of water over it, clearing away that portion of the rock lined over, the line of cleavage being 18 feet long. In a second instance of this nature a ledge of rock about 8 feet wide and 6 feet high stood out about 20 feet at right angles from the main rock. A charge of 50 lb. of lithofracteur was placed

against the base of the rock, and with 8 feet of water for a tamping was exploded with the result that the ledge of rock was brought down in fragments. Similar operations were successfully carried out with 5 lb., 10 lb. and 15 lb. charges.

The heaviest charge fired by the author at Jersey was one in connection with what is known as the South-East Rock, situate near the Hermitage Rock. In this case a charge of 115 lb., including the priming charge, was exploded against a wall of rock which was standing out from the main rock, but running in a line nearly parallel with its face, there being a space of about 5 feet at the opening, diminishing to nothing at the back. The site of this blast is shown in elevation at Fig. 2, while Fig. 3 is a side view showing the arrangement of the charge and tamping. The wall was about 20 feet high, 19 feet long and 12 feet thick; the base being exposed for a short time only at low water, and the rock being nearly submerged at high water, ordinary tides. This afforded the advantage of resistance due to a good head of water for tamping. Having prepared a charge of 100 lb. of lithofracteur, with a protected priming charge of 10 lb. attached, it was placed in position at low tide in the angle formed by the wall and the main rock. The charge was fixed in position with wedges and cross struts, and the whole was protected by twelve bags of sand and a heap of fragments of rock, some of large size. The safety fuse which, as a precaution, was in duplicate, was 30 feet long, and was led up the angle of the crevice and secured to a staple on the top of the rock. The charge was laid when the tide was out on a Saturday; the intention being to fire it at 9 P.M., when there would be a good head of water over it. The author made an attempt to land on the rock at that hour, which, however, proved ineffectual, there being a heavy sea running. The charge, therefore, had to remain under water during the Sunday, and on the Monday morning the author effected a landing at high water. He lighted the fuse, rowed away to a safe distance, and hung about awaiting the explosion. But the explosion came not. The fuse was a 30-second fuse, that is, it was timed to burn at the rate of a foot in half a minute. The explosion should, therefore, have taken place in about 15 minutes from the time of lighting. After allowing ample time for the explosion to take place, but without it occurring, there was nothing left for it but to put back ingloriously to shore and wait for low water to disclose the cause of the misfire.

Upon reaching the spot in the afternoon the first thing that met the view was the heap of stones and the twelve bags of sand washed down and spread about by the inrush of the waves.

The charge itself, fortunately, remained intact, the timbering having kept its place. The priming charge also remained, but the fuses, cracked and chafed, and with the unexploded detonators still fixed on their ends, were dangling in the air. The remedy was first, by way of precaution, to place 5 lb. more lithofracteur between the 10 lb. exploding charge and the deal cases containing the main charge, thus bringing the charge up to 115 lb., and to fix some extra protecting struts. New fuses were then capped, inserted in the primer, and led up the rock in a wood guttering, well-strutted and stayed. Surmising what had taken place, the author had provided for the contingency with men and materials, so that by the turn of the tide the re-adjustment was completed. Facilities for landing on the top of the rock were also provided in case of another squall. At 10 P.M. the author again rowed out, mounted the rock, lighted the fuses, and rowed away to a safe distance. In due course the low rumble of the sub-aqueous explosion was heard, which, together with the surface disturbance of the sea, indicated that the explosive had done its work. A cloud of spray was thrown high up into the air and showed distinctly against a clear sky. Although it was night and the weather anything but propitious, a number of persons assembled on the Victoria and Albert piers, from which they distinctly saw the effects of the explosion.

An examination of the spot on the following day showed that the charge had taken full effect. The wall of rock was lying on the bottom a heap of fragments, while a number of fissures in the rock under foot showed that the blast had also acted in a downward direction. The rock, as already stated, is a hard, dense syenite, weighing about 2 tons per cubic yard. It was a good test for the explosive, which had been exposed for 55 hours to the action of the wind and waves during five heavy tides. It was computed by the author and confirmed by Mr. Matthews, the engineer in charge of the works, that at least 400 tons of rock had been dislodged by the blast. This gives about 3½ tons of rock per pound of explosive used, which may be taken as a fair average of what it should do. In the big blast in a stone quarry at San Francisco in 1885, already referred to, the charge was 5½ tons or 11,000 lbs. of dynamite. It was estimated that 35,000 tons of rock had been displaced, which is a little over 3 tons per pound, thus practically agreeing with the author's experience. This average work of 3 to 3½ tons of rock per pound of explosive he has also obtained in other and smaller blasts.

Chambering a Deep Bore-hole at Ealing.

In the autumn of 1888 the author was consulted as to the desirability of exploding a charge down a deep boring for water in the chalk with the view of opening up the fissures and increasing the flow. Having advised that the blast should be made, the matter was placed in the author's hands to carry out. In this case Messrs. Le Grand and Sutcliff had sunk one of their artesian tube wells nearly 500 feet without obtaining the anticipated supply of water. The boring was situated on land adjoining the Grand Junction Water Company's Works at Ealing, on the border of the Brent Valley, for which company the bore was put down. The bore-hole was 470 feet in depth from surface, and was tubed for 326 feet of its depth with 5-inch tubing, and the water stood at 50 feet from surface. Below the tubing the bore-hole was $4\frac{3}{4}$ inches in diameter. The chalk was of a very hard and compact nature, and required sharp treatment. In order to avoid injury to the tube, and to get well into the chalk, it was decided to fire the shot 400 feet from surface. By this means a 350 feet head of water was obtained over the charge, giving a pressure of about 150 lb. per square inch. Lithofracteur not being obtainable, and having from experience formed a favourable opinion of carbo-dynamite, the author determined to use it in carrying out the operation. Carbo-dynamite is a nitro-compound, the invention of Mr. Walter F. Reid and Mr. W. D. Borland. It consists of 90 parts by weight of nitro-glycerine absorbed by 10 parts of a variety of carbon, the great porosity of which is indicated by its powers of absorption. Besides being a good absorbent, it is a good retainer of the nitro-glycerine, and is more powerful than dynamite, which consists of only 75 per cent. of nitro-glycerine absorbed into 25 per cent. of kieselguhr, which is merely an inert carrier, whilst the 10 per cent. absorbent in carbo-dynamite is itself combustible and adds to the explosive effect. Carbo-dynamite, moreover, is not hygroscopic, water apparently having no effect upon it, whereas water readily produces exudation in ordinary dynamite.

In the Ealing bore-hole blast, the charge was enclosed in a lead torpedo, and was fired by a submarine safety fuse, and a detonator. The torpedo was 2 feet 6 inches in length by 2 inches diameter, and was charged with 2 lb. of carbo-dynamite. The fuse was 12 feet in length and was timed to burn 1 foot in 30 seconds. To prevent accident or chance of a mis-fire from drawing, the fuse was protected by tubing. The author had ascertained that it would take two minutes to lower the charge by the hand winch to the intended position of

400 feet down the bore. Nor did he desire a quicker rate of descent in view of vibration and a possible hitch. It will therefore be seen that the explosion should not be expected to take place in less than four minutes from the time the torpedo had come to rest at 400 feet from surface. After a final critical examination the charge was lowered, the fuse being lighted at the top of the bore-hole. At the end of two minutes the 400 feet of wire rope had been payed out, and in $1\frac{1}{2}$ minute more the rebound of the wire rope indicated the explosion of the charge, which was confirmed by a noise of the water in the bore-hole which was in a state of violent agitation. It will thus be seen that the charge was exploded $2\frac{1}{2}$ minutes before the calculated time, which the author attributes to the action of the fuse being accelerated by the pressure of a heavy head of water upon it. There was no question that the fuse burned correctly to time in the air, as the author tested a piece before deciding on the length he should use for the blast. It illustrated the necessity of keeping well within the limits of safety in such operations. So far as the work done in chambering the bore-hole was concerned, the blast was a success, as chalk and water were pumped up for a day or two afterwards. The flow of water, however, was only increased a bare 15 per cent., and the conclusion therefore is that the chalk at that point is dense and fissureless.

Clearing Column Bases at Wapping.

It will probably be remembered by some present that about sixteen years since a steam ferry was started on the River Thames between the Tunnel Wharf, Wapping, and Church Stairs, Rotherhithe, on the opposite shore, with the view of relieving London Bridge of some of its heavy traffic. Untoward circumstances, however, supervened, and the steam ferry unfortunately had a short life, but not a very merry one. In course of time the landing stages on either side of the river had to be cleared away, and just to the eastward of that on the Middlesex side an extensive deep-water landing-stage or jetty was constructed for Middleton's Wharf Company, some of the materials of the ferry landing-stage being utilised in its construction. The columns of the ferry landing-stage, which had to be removed, extended down 18 feet into the bed of the river, and to avoid all risk of damage to craft they had to be cleared away to a depth of 6 feet below ground level. To this end the contractor for their removal hit upon the expedient of hauling on to them from the top with tackle until they snapped off. This method of treatment was successful in all but four cases, in which the columns

broke off at about the level of the river bed, and therefore constituted sources of danger to navigation.

In February 1890 the author was consulted by Mr. F. E. Duckham, an old Member of this Society, and consulting engineer to Middleton's Wharf Company, as to the feasibility of removing these awkward snags by blasting. Having advised their removal in this way, the author was commissioned to undertake their demolition. The tops of one pair of these stumps were 20 feet below Trinity high water level, and the tops of the other pair 22 feet 6 inches, as shown at Fig. 4, and 6 feet of these obstructions had to be removed, that is, each column had to be cleared away to about 6 feet or so below ground level. The columns were of cast iron, 3 feet 6 inches diameter by $1\frac{1}{8}$ inch thick, and filled in with concrete. The four stumps were 40 feet apart in line with the shore, that is up and down stream, and 15 feet apart in the opposite or across stream direction. The inshore pair, which were broken off just underground, were situate at low water line, and were only uncovered for a very short time, and at some tides not at all, while the outer pair, which were broken off about a foot above ground, had never less than 2 feet or 3 feet of water over them. It will therefore be seen that it was rather an awkward job to tackle, and one which necessarily occupied some time, as the stumps could only be got at for a short period, and at intervals of tides. Added to this the screw of the westward column of the outer pair was only 20 feet in a diagonal direction from the Thames Tunnel, so that great care had to be exercised in guarding against damage by the explosion to the outer works of that structure.

The method adopted was to bore a 3-inch hole in the centre of each stump to a depth of 7 feet into the concrete. The boring tool was guided by a 3-inch diameter wrought-iron tube, which was driven down into the hole as the boring progressed, work being carried on chiefly under water. When the hole was down to the required depth, the wrought-iron liner was fixed in position and served as a guide for the charging tube, which was subsequently inserted. Owing to the interference of tides and the wash from steamships, these holes took a long time to complete. To get at the outer pair of stumps, a staging reaching just above low water level was rigged up over each with a guide for the boring tool. In course of time the bore holes were ready for charging, and taking one stump first, a 16-feet l eg th of $1\frac{1}{2}$-inch strong tin tubing was fixed within the iron liner in the bore-hole, and left for the rise of tide, when it was intended to insert the charge in the bore-hole through the tube. The tide was allowed to rise within a foot of the top of the

tube, when the working party rowed out to charge the hole. So strong was the tide, however, that just as the boat reached the tube, which was seen to be canted over, it broke off close down by the hole, and was carried away.

Two 16-feet lengths of $1\frac{1}{2}$-inch wrought-iron tubing were then prepared, and at next low water were inserted in the pair of stumps nearest the shore and held against the tide by ties. When the tide had risen sufficiently high, an 8-oz. charge of carbo-dynamite was dropped down one of the tubes and rammed well home with a 17-feet loading stick. A 2-oz. priming charge, attached to an 18-feet length of capped fuse, was then inserted, the fuse lighted, and the boat pulled out into mid-stream. A thirty-seconds fuse was used, and in due course there were indications of the explosion having taken place. An attempt was then made to charge the second hole, but the cartridges jammed about a foot from the mouth of the tube, and, the tide rising rapidly, it had to be abandoned. When the tide allowed, which was at midnight, the top length of the tube was unscrewed and the cartridges extracted. Upon examination it was found that there were iron splinters projecting inside the tube, which effectually barred the passage of the charge. It was satisfactory to find that the carbo-dynamite was perfectly intact and free from exudation, notwithstanding its protracted immersion in water. At 8 A.M. the next morning, the obstruction in the tube having been removed, it was screwed in position, the hole charged, and the charge successfully fired. On the morning of the following day the third hole was charged and blasted, and at midnight the fourth hole, the operations being carried out in the same way in each instance. It should be stated that temporary moorings were laid down at each stump, in order that the boat might be kept steady within a few inches of the tube. Of course, as the tide rose, the mooring rope had to be slacked out in order to preserve a constant distance between boat and tube. Great care was necessary in slacking out, as a bump from the boat against the tube would have upset the arrangements, and might have led to a premature explosion. The charge was the same in all cases, namely, 8 oz. of carbo-dynamite with a 2-oz. primer.

The results of these blasts were in every way satisfactory, the lower end of the wrought-iron tube in each instance being rent into strips for about 2 feet up, and bulged out claw-like to a diameter of about 18 inches. The wrought-iron liner was shattered, and the concrete in the cylinders in the region of the explosion disintegrated. The cylinders were broken up to the depth of 7 or 8 feet, and some portions were removed by hand, whilst others were extracted by a pair of grabs and the

wharf crane. A dredger was afterwards set to work and further portions of the cylinders were dredged up. In short, the demolition was complete. Not the least surprising part of the operation to some was the noiselessness of the explosions. It was thought by some that there would be a sudden roar, an upheaval of water, and a scattering of the débris in all directions. There was, however, but little indication of the blast, even to practised ears. When the first stump was blasted, Mr. Rankin, the engineer in charge of the wharf machinery, was on the look out for some startling effects. Having neither seen nor heard anything, he was greatly surprised upon the landing of the working party to learn that the blast had taken place, and could hardly be persuaded that we had not had a misfire. He, however, expressed greater surprise when the next low tide revealed the shattered stump, which the men were clearing away.

As a matter of course the Thames police manifested a special interest in the proceedings, especially at each blast. Their galley hovered around while the holes were being charged, and when the fuse was lighted and we rowed away to a safe position, they betook themselves to a much safer one, doubtless with the praiseworthy object of making sure of being able to render us personal assistance should our boat be blown out of the water. It is hardly necessary to state that the Thames Tunnel still exists unimpaired, a standing testimony to Brunel's genius.

Demolition of a Bridge at Reading.

In the course of widening the Great Western Railway between Maidenhead and Didcot, several brick and timber bridges had to be demolished and superseded by structures on more modern principles. The difficulty which had to be contended with in the removal of these bridges was that they were over the main line, and it was a *sine qua non* that the traffic should be in no way interfered with or obstructed. It was originally intended to put in skeleton centre ribs with laggings under the arches, and upon these to remove the arches piecemeal. There was not, however, sufficient room between the minimum structure gauge and the soffit of the arches to introduce the ribs and lagging, so that plan had to be abandoned. Among others was one of Brunel's brick over bridges, known as Mustard Lane Bridge, carrying the roadway across the line at 32 m. 71½ c., at the east end of Sonning cutting, near Reading. The contractors for that portion of the works in which the bridge was situated were Messrs. Lucas and Aird, whose engineer, Mr. Herbert Ashley, consulted the author in the

spring of 1891 as to the feasibility of removing the structure by blasting. Having inspected the bridge and satisfied the contractors on that point, and having submitted a scheme for carying out the operation, the author was instructed to proceed with the work.

The bridge consisted of three semi-elliptical brick spans of 31 feet 6 inches and 28 feet 6 inches high from rail level to soffit, with brick abutments, parapets and wing walls, the cutting here being 30 feet deep. The two piers were 5 feet thick, and the bridge was 19 feet wide between the parapets. The lines of rails passed under the centre span, the two side spans being over the slopes of the cutting. An outline elevation of the bridge, with the parapet removed ready for blasting, is shown at Fig. 5. The scheme of demolition propounded by the author consisted in first cutting through the crown of each of the side arches by blasting, and then through that of the centre arch. This would leave the piers standing with a half-span attached on either side. Then by simultaneously firing charges on the inside of the two piers at the springing of the centre arch, it was conceived that the piers would be thrown outwards on to the slopes of the cutting, the two halves of the centre arch falling on to the rails. This point was important in view of clearing away the débris, as the time during which the work of demolition had to be carried out and the line cleared was very short. It was, moreover, ordered that no explosive was to be placed in position until a given train, which marked the commencement of the longest interval, which was two hours, had passed. The bridge was prepared by removing the road metalling and the parapets, and the holes were drilled as shown in plan at Fig. 6. It will be seen that there were five sets of four holes, marked respectively A, B, C, D and E.

In deciding upon the quantity of explosive to be employed, while using sufficient to bring down the bridge, great care had to be taken not to damage the telegraph wires nor to injure a cottage which was situate just at the end of the bridge. Carbo-dynamite was the explosive selected by the author for the work, and it was decided to charge each of the holes in row A with 8 oz., those in row C with 6 oz., and those in row E with 6 oz. These charges were for cutting through the crowns of the three arches, the bore holes for which were 13 inches deep, just passing through three out of the five rings of brickwork. In the two series of holes B and D, which were 5 feet 6 inches deep, and were drilled in the haunches of the central arch, the charges for the top and bottom holes were each 16 oz., and those for the two intermediate holes 14 oz. each. The quantity of carbo-dynamite used was therefore 12 lb. 8 oz., plus 20 1-oz.

primers, which brought the total to 13 lb. 12 oz. The charges were tamped with dry sand.

The method of exploding the charges simultaneously in three sets of fours in the crowns of the arches and one set of eight in the two haunches was as follows:—A length of instantaneous or lightning fuse, burning at the rate of 150 feet per second, was attached to the detonator in each priming charge, and was led into a coupling box. Here they were coupled up to a length of ordinary 30-second safety fuse, which, on being lighted, burned down to the group of instantaneous fuses, igniting them and exploding the detonators, and through them the charges. The arrangements of the fuses for exploding the charges in the crowns is seen at Figs. 7 and 9, and that for exploding the charges in the haunches at Fig. 8. The safety fuse is marked S, and the instantaneous fuse I. The simultaneous explosion of the various charges was necessary in order, firstly, to get the maximum effect out of the combined charge; secondly, to save time; and thirdly, to prevent the possibility of the explosion of one charge separating an unexploded one from its fuse, or otherwise dislodging it so that it might constitute a source of danger to the workmen when clearing away the débris.

The day fixed for the demolition was Sunday, April 19th, 1891, and everything was in readineas for charging the holes at 2 P.M., at which hour the train which marked the commencement of the longest interval was to pass. As a matter of fact, however, the train was 15 minutes late, but directly it had passed the holes in row A were charged and simultaneously fired, the crown of the arch being cracked completely through. Rows C and E were then successively charged and fired, with similar satisfactory results. Then came the heavier charges in the haunches, which were likewise put in and fired. It was hoped that they would have had the desired effect of throwing the piers over on to the slopes of the cutting and permitting the two halves of the centre span to fall inwards on to a bed of straw below. Unfortunately this was not the case, for the piers moved slightly round upon their footings, and the two halves of the centre span jammed at the front, the whole structure, however, being broken up into numerous parts and ready to fall down directly the nip at the front was overcome. To this end heavy ropes were thrown over the rim of the broken arch just at the bite, and attached to a goods locomotive which, with the ropes, had been provided in view of such a contingency. After two breakages of the ropes, the bridge and one of the piers came down with a crash, sending clouds of red dust into the air. The want of success in bringing the bridge clean down by

means of the explosive was doubtless due to the circumstance that the final charge was just a little too small. This was the result of anxious carefulness not to injure the telegraph wires or the adjacent house. On mounting to the top of the bridge after the explosions, to arrange the hauling tackle, the structure was seen to be rent and fissured in all directions. It was also clear that a trifle stronger charge in each of the holes in the haunches of the centre arch would have resulted in its complete, instead of its partial collapse.

As soon as the bridge was down a gang of about 40 men set to work to clear the down line, which was more free from débris than the up line. A large portion of one pier had deposited itself over the latter, while the other pier was only slightly shifted from its normal position. As the larger masses of brickwork were broken up, the débris was loaded into trucks and the trusses of straw finally cleared off, the down line being opened for traffic in about two hours from the collapse of the structure. This was some time after the period assigned, and consequently the traffic was delayed. As soon as the way had been cleared the waiting trains were passed through, and the traffic both up and down was carried on over the down rails. The removal of the wreckage was no easy matter, as Brunel's brickwork held splendidly together, the pier on the up line obstinately resisting demolition on a large scale, and yielding only to piecemeal disintegration and removal. It was a fine night, though rather cold, and a liberal supply of refreshments being provided by the contractors, the navvies and labourers stuck to their work throughout the night as only English navvies and labourers can stick. Nor is less to be said for the company's sectional engineer and other officials who, with the contractor's engineer, remained by with the author and his colleague, Mr. Walter F. Reid, all night. By 7 o'clock on Monday morning both lines were cleared, and the removal of the wreckage sufficiently advanced to permit of the finish being left in the hands of subordinates, who had arrived to relieve guard. Not being able to get at the quantity of brickwork moved, the author can only summarise the result by stating the broad fact that one of Brunel's bridges, consisting of three spans of 31 feet 6 inches each over the Great Western Railway, was demolished by a divided charge of 13 lb. 12 oz. of carbo-dynamite. With the exception of the delay caused to the traffic, the result was considered to be most satisfactory.

As regards the quantity of explosive employed to perform a given amount of work, the result compares favourably with that in the case of another bridge in the Sonning Cutting, which was subsequently demolished by blasting. This bridge

came within Messrs. Lucas and Aird's contract, and was taken down on September 13, 1891, but not by the author. The bridge had one semi-elliptical arch of 30 feet span and a roadway width of 18 feet 3 inches, carrying a road over the railway. The bridge was stripped in the same way as that removed by the author, in addition to which the brick and concrete backing was cleared away from both sides of the arch. In this case the total charge was 23 lb. 12 ozs. of tonite, disposed in thirty holes. As a matter of course, the disintegration of the structure was more complete, and the clearance of the débris, therefore, effected more quickly than in the author's case, as, indeed, it should be with $23\frac{3}{4}$ lb. of explosive for one arch, as against only $13\frac{3}{4}$ lb. for three arches. In view, however, of the delay that took place in the clearance operation after the blast in the author's bridge, he would undoubtedly slightly increase his charges to a gross amount of about 16 lb. in the case of a similar demolition, other things being equal.

As regards the precautionary measures taken, the author may mention that in order to prevent damage to the rails by the projection downwards of the bottoms of the shot holes, or by the fall of the bridge, the permanent way was protected by a double layer of trusses of straw, placed crosswise one over the other. The author, however, would not adopt this method again, for the reason that it hinders the removal of the smaller portions of the débris. In place of straw he would use stout timbers for protecting the rails from injury. A further precaution was the presence of a staff of telegraph men with tools and materials for repairing any damaged wires, but whose services fortunately were not required, although a few brickbats were hurled through the air at each explosion. The windows of the adjoining cottage were opened and the tenants were temporarily evicted. No damage, however, was done here, only a few fragments of brick falling harmlessly, although not noiselessly upon the slated roof. The reason for this immunity was mainly due to the fact that the holes were all put in vertically, and that the charges were well distributed.

Selection of Explosives.

In the course of his experience the author has had to experiment with, and to demonstrate on a working scale the practical character of a considerable number of high explosives, including dynamite, roburite, securite, bellite, von Dahmen's safety dynamite, fortis powder, Hengst's powder, lithofracteur, and carbo-dynamite It will be seen, however, that for his practical work he has selected the two latter only. This is not because

of their greatly superior power over the others, for there is not, in his opinion, such a very wide margin between any of them as regards strength as is sometimes claimed for them. There is, however, a difference between some of them as regards the way in which they exert that strength. Let us take, for example, dynamite, which is the oldest and best-known high explosive (but which is now gradually being superseded by other nitro-compounds) and compare its action with that of lithofracteur, which at one time promised to become its formidable rival. The explosion of dynamite takes place with flashing rapidity, and its full power being so instantaneously developed, its action is more or less locally intensified, resulting in a smashing effect within a comparatively limited area. In lithofracteur, however, the power is developed a little more slowly, and the retardation causes it to act with greater lifting and rending effect than dynamite, and its power is utilised in doing work over a wider area. There are also two other features which commended lithofracteur and carbo-dynamite to the author in the circumstances under which he employed them. These are plasticity and resistance to the action of water. Plasticity enables an explosive to be pressed well home into a bore-hole of larger size than the cartridge or one of irregular shape. It can also be made to readily conform to the shape of a cleft or crevice in which it may be desired to use it. Capability of resisting the action of water, too, is of the greatest importance in sub-aqueous operations, or in the event of accidental exposure to water such as occurred with the author both at Jersey and Wapping. Water, moreover, from its incompressibility, forms an excellent tamping, and in vertical holes and holes bored at an angle which permits of the water being retained, it is not unfrequently used to advantage with explosives which permit of it. In dwelling upon these features, the author would by no means be thought to decry the excellent qualities of the other explosives mentioned by him, and still others to which he has not referred. There are circumstances in which the use of lithofracteur and carbo-dynamite would be inadmissible, and where some of the others alone could be employed.

Danger Risks.

In carrying out blasting operations it is of the first importance to have a reliable colleague. He should possess a cool head, a steady hand and a quick judgment. Both in his work with lithofracteur and carbo-dynamite the author has been fortunate in having the co-operation of gentlemen possessing

those desirable qualities. In the former instance he had for a co-worker Herr Jacob Engels, the inventor of lithofracteur, and in the latter Mr. Walter F. Reid, the inventor of carbo-dynamite. To the latter the author is indebted for several practical suggestions as regards details of the operations. It is hardly possible for those who have not had experience in the class of work described in this paper to realise the thousand and one points that present themselves for careful consideration during the organisation of a blasting operation, nor the deep anxiety that pervades the mind when the supreme moment of its execution arrives. The most thoughtful care and the keenest watchfulness have to be exercised throughout, lest at any moment a trifling slip should be the cause of failure, or worse, of dire disaster. Such being the general mental condition antecedently to the event, it may be imagined what a grateful sense of relief is experienced upon the attainment of a successful result.

Nor are risks of accident absent during the actual execution of blasting operations, either through the stupidity or the want of nerve on the part of workmen. For instance, when carrying out some torpedo experiments at Quenast the author had a couple of boats conveying to mid-stream a light raft, under which was a heavy charge of lithofracteur with the exploding gear attached. The raft was resting on the gunwale of each boat, and the author's instructions to both crews were to lift and lower it gently into the water, a work very easily performed. The raft was lifted gently enough, but at the author's signal to lower, it was simply dropped down on the water and the boat's crews took to their oars and rowed away for their lives. The author at length got one man, who had a little more courage than the rest, to pull him quietly out to arrange the charge and light the fuse. Another instance occurred in the Isle of Man, where the author was doing some blasting in connection with the Douglas Harbour Works for Sir John Coode. He had charged two big holes in a 16-inch ledge of rock with about 1 lb. of explosive each. The ledge was his platform, and he had a 10 or 12 feet vertical wall of rock before him, and 18 feet of water behind him. The water was just up to the level of the ledge of rock, and having lighted his two fuses he put his hands on the gunwale of the boat to embark, when the boatmen instantly pulled off, although they were well aware that they had five minutes in which to clear out. As a consequence the author, with a heavy pair of jack-boots on, slipped into the 18 feet of water. As he did not release his hold of the boat, he was quickly got inboard, plus a gallon or

two of sea water stowed away in the jack-boots. In other cases the author has encountered risks, not from fear but from sheer recklessness.

The Santander Explosion.

It was not the intention of the author to touch upon the subject of involuntary or accidental explosions, for the reason that they have been recorded by him in previous papers. If even they had not been so dealt with by him they would hardly have been admissible in the present communication, as they cannot rightly be classified under the head of practical examples of blasting. The unprecedented character, however, of the awful calamity that has recently befallen the busy port of Santander in Spain, and the deep and widespread interest manifested with respect to it will, the author feels assured, justify a record of the lamentable occurrence on the present occasion. A reference to it here, moreover, affords the author the opportunity of expressing the deep sympathy which every Member of the Society, in common with himself, must feel for the sufferers by that terribly sudden visitation. And this sympathy may be appropriately extended to the sufferers from the diabolical outrage perpetrated in the Liceo Theatre, Barcelona, by the explosion of a bomb in the midst of the unsuspecting and unoffending audience, on November 7th, only four days after the Santander catastrophe. Fearful havoc has been caused by accidental explosions which have occurred from time to time in the past, but none, so far as the author's memory serves him, have been so calamitous as that at Santander, when a dense crowd of human beings, who had been attracted by the unwonted sight of a burning ship in their harbour, were in an instant reduced to a heap of maimed and writhing creatures, mingled with disfigured and dismembered corpses, besides the crowds who were blown from the surrounding shipping into the water, while their town was rapidly set ablaze at at least a hundred different points. The harrowing details which have been given of the occurrence mark it as the most frightful catastrophe of its kind that has ever happened. The loss of life is estimated at over five hundred persons, and that of property at many thousands of pounds, perhaps approaching millions. The absolute number of those who have perished can never be known, whilst the wounded form a heavy list of over two thousand persons.

The particulars of the disaster have been variously stated, for at first there was great difficulty in obtaining definite infor-

mation owing to the circumstance that many of the public functionaries are amongst the victims, as well as those who had charge of the ship. As far as can be ascertained, however, it would appear that on Friday, November 3rd, 1893, the steamship *Cabo Machichaco* was discharging her cargo alongside a quay in the Port of Santander. That cargo consisted of 2000 tons of iron, 12 tons of sulphuric acid, a number of casks of petroleum, some casks of spirit, and 1720 cases or 43 tons of dynamite. We here have a heterogeneous collection of materials, constituting a cargo of the most dangerous character conceivable. It appears that the dynamite was not contraband, as at first supposed, but that the whole cargo was duly cleared by the Custom House authorities, when the ship left Bilbao. At 3 P.M. on the day mentioned a fire broke out in the coal bunkers, and as soon as the alarm was given, care was taken to at once land twenty cases of dynamite which were consigned to Santander, the remainder being consigned to other ports. As the fire could not be got under, it was determined to tow the *Cabo Machichaco* out into the Bay of Biscay, and let her burn out there. A tug boat was made fast to her for this purpose, but the effort to get her away from her moorings was unsuccessful. It was now an hour and a half since the outbreak of the fire, and although every effort was made to extinguish the flames without success, it does not appear to have occurred to anyone during that time, even to those who knew the nature of the cargo, to scuttle the vessel and thus prevent a disaster which they must by degrees have known to be inevitable. But nothing of the kind was attempted, and at 4.30, with crowds of spectators and swarms of busy helpers around, the fire appears to have reached the petroleum, which then exploded. This was rapidly followed by a second explosion, said to be the ship's boilers, and this again with equal rapidity by a third explosion of a terrific character, which was undoubtedly the dynamite. The burning ship with the tug alongside, on board of which were a number of townspeople curious to see a burning ship towed out to sea, at once disappeared. The quay was completely wrecked, and the crowd of human beings which thronged it were blown into the air and scattered around on sea and shore, while flaming fragments of timber were projected over the town, setting more than a hundred houses on fire. Numerous ships and small craft in the vicinity of the *Cabo Machichaco,* together with their crews, were blown to pieces, whilst others were set on fire by the burning fragments. The distance to which pieces of wood and iron were hurled is shown by the fact that a man was killed by a fragment at Penancestillo, about a mile from the harbour. A local railway train which entered the station at the moment of the explosion

was wrecked and ignited, and many of the passengers are reported to have perished. When darkness set in the sky was lurid with the reflection of uncontrolled fires in various parts of the town, no attempt being made to cope with the conflagration, but everyone abandoning the city for the fields and outlying villages. A night of terror was passed, during which hundreds were searching amongst the dead by the glare of the burning city for lost relatives and friends, and on Saturday morning Santander, which 24 hours previously had been counted among the most flourishing towns in Spain, resembled a city of the dead.

Quitting these horrors, which the author would have passed over more lightly but for the magnitude of the disaster, let us see what the quantity of dynamite was that caused this havoc. The total quantity stated to have been on board the ill-fated vessel was 1720 cases, of which 20 cases were landed upon the outbreak of the fire. This leaves 1700 cases, which, reckoning the usual quantity of 50 lb. to the case, give 85,000 lb., or $42\frac{1}{2}$ tons, the ton of explosives being 2000 lb. It appears, however, that 600 cases or 30,000 lb. = 15 tons, were subsequently found by divers to be unexploded and were afterwards recovered, loaded in barges, towed out and discharged in deep water in the Bay of Biscay. This reduces the bulk to 1100 cases = 55,000 lb., or $27\frac{1}{2}$ tons, a quantity capable of producing appalling results. In an ordinary blasting operation, such as some of those carried out by the author in Jersey, this quantity of dynamite should displace about 200,000 tons of rock, reckoning the work done on the basis of the author's experience, which is $3\frac{1}{2}$ tons per pound of explosive employed.

It is a matter for thankfulness that the whole of the 1700 cases were not exploded, or the results, bad as they were, must have been much worse. How it was that the 600 cases escaped explosion the author cannot understand, except upon the hypothesis that the explosions prior to that of the dynamite so broke the ship's back that the 600 cases dropped away into deep water before the explosion of the remainder took place. It is certainly marvellous that these cases were not exploded, considering the magnitude of the explosion and their proximity to it. The author has already expressed his surprise that it did not occur to those in charge of the vessel to scuttle her, when they found they could not subdue the conflagration on board, seeing that they must have known the risk they were running. But, although they may have known the risk, they may not have realised it, nor believed in it, for, unfortunately in the early days of dynamite, and even later on, the often fatal doctrine was promulgated that that compound would only burn

under the influence of fire, and that nothing would explode it except a proper detonator. Endeavours have been made in later times to cause people to unlearn this foolish doctrine, but it still lingers, and only a year or two since the author was present when this doctrine was preached and practised by one who should have known better, but fortunately without disastrous results. The doctrine invariably preached and practised by the author is that explosives are only comparatively safe as long as they are treated as absolutely dangerous. There is no reliance whatever to be placed on the theory that dynamite and many other high explosives can be burned without exploding. Dynamite will explode and has exploded when subjected to the necessary temperature, or to certain conditions other than those of explosion by a detonator. This point has been illustrated over and over again with fatal results, and the ignorance, crass stupidity and recklessness occasionally shown by those who are accustomed to the daily use of high explosives, appears so incredible that the author hopes it will prove both interesting and instructive if he gives two examples under the not inappropriate head of

The Romance of Dynamite.

Were the writer of a "shilling shocker" to introduce into his plot the instantaneous death of a young newly-married couple by an explosion of dynamite in the stove of their sitting room, the explosion being brought about by the bridegroom's brother leaving the dynamite baking in the oven of that stove for three days, he (the writer) would be deemed guilty of going a very long way beyond the bounds of human possibility in his search after the sensational. And yet, in introducing such an incident, that writer would in no way overstep the limits of possibility, but would be strictly within the truth. Such an occurrence, incredible as it may appear, took place in the village of Soothay, Silverdale, North Staffordshire, about a month since. At half past five in the afternoon of Monday, November 6, Charles Poulton and his wife, to whom he had only been married a few days, were sitting in their cottage together with an elder brother of Poulton's who also resided there. Without the slightest warning a terrible explosion took place, which nearly wrecked the house, literally blew the young wife to pieces, fatally injured the husband so that he died a few hours afterwards, and seriously injured the brother. Upon being questioned as to the cause of the explosion, the elder Poulton stated that on the previous Saturday he had placed a charge of blasting gelatine in the oven to thaw, and had forgotten all

about it until the explosion took place. Truly truth is stranger than fiction, and this adage has often been present to the author's mind in connection with dynamite accidents.

The annual reports of Her Majesty's Inspectors of Explosives, which the author consults from time to time, lift the veil from dynamite "accidents," so-called, and reveal instances of recklessness and suicidal ignorance which appear incredible, and would not be believed were they not officially authenticated. Not the less do accidents arise from sheer stupidity, which still goes blundering on in spite of the many warnings it receives. The most fruitful source of accidents with dynamite is the thawing of the cartridges, which solidify and become inert at a comparatively high temperature, namely, about 40° Fahr. To thaw the cartridges tin warming pans are, or should be, provided, and if used with ordinary care they form a safe and efficient means of carrying out this operation. They are constructed on the principle of the glue pot, the cartridges being placed in the removable portion and covered up, the bottom part being filled with warm water. So reasonably safe is the use of this contrivance that the author can only recall one instance of an accident occurring in its use. On the other hand, a very large number of persons have been killed, and a still larger number seriously injured, and much property destroyed through the improper thawing of dynamite. Taking into consideration the fact that users of dynamite must all be more or less aware of the danger of carelessly treating it, and they are all aware of its enormous power, the history of the steps taken for courting accident—the author might almost say, the precautions taken to ensure accident—reads almost like a romance. Hence the heading of this section of the author's paper.

The ingenuity exercised in devising means for thawing dynamite in the most unsafe way possible is certainly very remarkable. The favourite methods of effecting this object have generally been frying, boiling, toasting and baking the cartridges as in the case already referred to, and these processes are sometimes carried out in vessels of the most fantastic character. It, however, remained for human ingenuity—grossly misdirected—to devise yet another method besides those just enumerated, of rendering an explosion inevitable. This method consisted in steaming the cartridges over hot water in the same way that potatoes are steamed. The case, which is recorded in the Report of H.M. Inspectors of Explosives for 1890, is so unique that the author cannot refrain from summarising it upon the present occasion. The explosion occurred at the Colwill Quarry, near Egg Buckland, Devonshire. The method adopted by the renter, Edward Gullett, was to take an old 28-lb. paint

drum, half fill it with water, and stand it on a sledge-hammer head which rested on the smithy fire. Over the top of the paint drum was tied a piece of canvas sacking, and on this the cartridges were steamed. "You see," said Gullett, when giving his evidence at the inquest, "the nitro-glycerine will leak through the bag if overheated," thereby implying that it was an excellent arrangement for getting rid of any exuded nitro-glycerine. And this was the method he and his men adopted for thawing frozen cartridges ever since he had used dynamite. At last the inevitable explosion came and killed two of Gullett's work-men. The only variation in the process appears to have been that devised by one of the deceased men, who, before he died, stated that he had sometimes thawed cartridges in an old straw hat, which he suspended in the top of the pot in place of the sacking. According to this unfortunate sufferer, he was heating the water when it—i.e. the water—exploded, and he attributed the explosion to the fact that the "nourishment" had got into the water from previous cartridges. Nothing here is wanting to point conclusively to the cause of the explosion. It was a simple case of abstraction of nitro-glycerine, as carefully arranged for as it could have been in a chemical laboratory, with the exception of the excess of heat applied. The nitro-glycerine would, by the action of the steam, exude from the cartridges and would filter through the canvas or the straw hat into the pot. Here, with its specific gravity of 1·6, it would accumulate at the bottom of the water, which latter would act as an effective tamping to the charge. The pot being placed over the smith's fire, the nitro-glycerine would speedily reach its exploding temperature, and the whole apparatus would form a water shell precisely on the same principle as that which Sir Frederick Abel some years ago advocated for artillery purposes. The shell was filled with water, in which was a small charge of gun cotton, and the explosion was effected by a primer and fuse. The author saw some of these shells tried with good effect in the artillery experiments at Okehampton in 1875.

A great deal of misapprehension and misplaced confidence has been caused by the fact that small quantities of unconfined nitro-glycerine and explosives containing it as their chief constituent, will sometimes burn quietly away when ignited by direct contact with a flame. It has, therefore, been thought that if this was the case no ill effects could arise from simply heating it. This idea, as the author has already observed, is a terribly mistaken one. If a cartridge of dynamite or its congeners is lighted or placed in a fire, it may burn harmlessly away. But if a similar cartridge is placed on the hob of a stove or an oven, and gradually heated up to its exploding point,

which is from 350° to 400° Fahr., a violent explosion will almost inevitably result, and before that point is reached the explosive will become extremely sensitive to the slightest shock. Nobel states that when dynamite is heated to 440° Fahr. it is liable to explode. But Nobel is the apostle of dynamite, and is liable to look a little too favourably upon its faults. Colonel Cundill, one of Her Majesty's Inspectors of Explosives, gives 360° Fahr. as its exploding point, and Eissler, in his work on explosives, states that when dynamite is heated to 350° Fahr. a dime falling upon it will explode it.

It is only fair to point out that the causes of some of these wretched occurrences are to be sought for beyond the poor miners or quarrymen. It sometimes happens either that the agent for the explosive fails to impress upon a purchaser its dangerous nature under certain conditions, and to supply him with a proper thawing apparatus, or that the purchaser from parsimonious motives fails to provide his men with one. Again, it has occurred that a manager, although he has provided the men with warmers, fails to see that they are used by the men in place of their own reckless methods. It is well, then, that the Home Office authorities should look keenly beyond the unlucky, ignorant labourer to some responsible person, a verdict for manslaughter against whom might act as a salutary warning to those who care little beyond selling explosives and pocketing the profits, or conducting their business on the most parsimonious principles. Such reprehensible conduct as the author has indicated, and which has actually occurred, can only pass without censure when it passes without observation.

In conclusion, the author would observe that although he has travelled somewhat outside the scope of the title of his paper, he trusts that the wide public interest which attaches to the subject of the latter portion of it will justify him in his departure from the programme laid down in his opening remarks. To all either the use or the misuse of explosive compounds must form a matter of interest. While their accidental explosion is to be deeply deplored, and their employment by misguided fanatics in the execution of diabolical outrages against society as deeply deprecated, it must not be forgotten that, used for the legitimate industrial purposes for which they are intended, they rise to the dignity of an important factor in the material progress of nations.

DISCUSSION.

The PRESIDENT said it was his pleasing duty to propose a vote of thanks to Mr. Nursey for his excellent and interesting paper. With the previous papers which Mr. Nursey had contributed to the Society on the subject it formed an interesting record of explosives. He hoped the paper would be well discussed, and no doubt the remarks of the speakers would be of an equally interesting character.

The vote of thanks was accorded by acclamation.

Admiral COLOMB, in opening the discussion, first congratulated Mr. Nursey on producing a paper of such an attractive character. The question of dealing with high explosives was one of the most important before us at the present day. It was brought into prominence by the execrable use which was made of explosives. Moreover, such an explosion as that which had lately occurred at Santander gave rise to the question whether we had yet got the amount of safety which might be obtained in the development of such compositions. The latter part of the paper showed how very easy it was to destroy life and limb by the employment of explosives which evidently required exceeding great care in manipulation. The author had dwelt almost wholly upon nitro-glycerine compounds, although he mentioned others. Perhaps in his reply to the discussion he would deal more completely with the other classes of explosives, especially those which were known as the Sprengel class. He should like to hear from the author what was his experience of explosives of that class, and why he seemed to prefer nitro-glycerine compounds; and also whether he ran the greater risk of using the latter simply on account of their greater convenience. Roburite, the explosive which he (the Admiral) was most familiar with, had been used to an immense extent all over the world, and, so far as was known, it was as harmless by itself as brown sugar. He did not mean to say that every possible experiment had been tried with it, but no one had yet succeeded in making it explode unless the proper detonator was attached to it. That seemed to be a characteristic of the explosive, which was quite certain to cause it to make its way, however slowly it might proceed. During all the years that roburite had been in use, no instance had occurred of any amount of carelessness causing an explosion unless a detonator was associated with it. It might be possible to explode roburite if it was subjected suddenly to enormous heat. Every other form of experiment had been tried with it, and, as far as was known, there was no reason to believe that it was possible to explode it by any means except by the legitimate detonator.

The blasting operations which Mr. Nursey had described were all of the greatest possible interest, and he (the Admiral) was sure that everyone must be struck by Mr. Nursey's remarks as to the care which was required to balance the amount of the charge with the amount of work which was to be done. The success which had attended Mr. Nursey's blasting operations showed that he must be very skilful in estimating the weight of explosive necessary to do the work. It might be interesting to the meeting to note one or two examples of blasting with roburite as a Sprengel explosive. He had before him a report made by the manager of a mining company in New Zealand. It was dated May 3, 1893, and was as follows:—"It gives me great pleasure to testify to the thorough success of roburite as a blasting medium in bulk. I have employed no other explosive for daily use in mines, in charges of from 2 lb. to 4 or 5 lb, for more than a year, in which charges it has given complete satisfaction." The letter went on to give details of blasting operations. One of these operations was amongst the largest blasts which had been made with roburite. The substance worked upon was an auriferous cement, peculiar to the New Zealand goldfields. Two charges of 700 lb. and 300 lb. respectively, were fired simultaneously by electricity. The resulting explosion brought down a mass of cement of more than 20,000 tons, and crushed and shattered a still larger quantity behind, which could easily be removed by hand. In that, as in other operations of a similar nature, roburite was found to be from three to four times as strong as gunpowder, weight for weight. The objections to it were that it was of light specific gravity, and that it was hygroscopic; but the hygroscopic character, which troubled its producers very much at first, was scarcely ever heard of now. The tendency to take up water had disappeared, as an inconvenience in practice. The only objection which was now heard concerning roburite was that it did not possess the quality of plasticity, which Mr. Nursey had mentioned. It could not be forced into holes of irregular shape unless it was put in in bulk. It would, however, stand moderate exposure in bulk. An interesting blasting operation was carried out with roburite in removing the wreck of the *Gambia*, which was an eyesore and a trouble. The wreck was off Port Elizabeth, in South Africa. The *Gambia* was a large iron ship, and she showed at low water. The roburite which was used was prepared at the works of the company. Each charge was encased in a waterproof covering of special construction, placed in position by divers, and fired by electricity. Over 1100 lb. of roburite was employed. This was made up into 100 cartridges of from 1 lb. to 16 lb. each,

according to the amount of resistance to be overcome. The work may be estimated to have taken twelve full working days, by which time every vestige of the wreck had disappeared. The ingredients were manufactured in England, sent out separately and mixed together on the spot. Mr. Nursey did not seem to take kindly to electricity as a means of ignition. He (Admiral Colomb) always laid great stress on electricity, especially for mining work. He thought that accidents were very much more likely to happen by other methods of firing.

Mr. Biggwither said he had come from Lancashire in order to be present at the meeting, as he was personally interested both in the manufacture and in the use of explosives. He had not been disappointed with the results of his journey, for he had learned a great deal that evening. In following Mr. Nursey's paper it struck him that the quantity of explosive which he put down the bore hole of which he had spoken, namely, 2 lb. of carbo-dynamite, was rather too small. If he had put a larger charge, and repeated the charge at a distance from the first shot, he would have probably got a better result as far as water was concerned. Of course it did not follow necessarily that water could be obtained by torpedoing in an artesian well. He had fired shots in a bore hole at Ford for the Herne Bay Water Company. The hole was 476 feet deep from the surface, and 416 feet from the bottom of the well At the bottom it was about 5 inches in diameter. The first shot was fired at the bottom, under a head of 416 feet of water. The well itself had been pumped dry. The explosive which he used was roburite. The torpedo was made of a tube 4½ inches external diameter, and 5 feet 2 inches long. The ends were closed with a cast-iron plug screwed in the pipe, the plug and the tube having been previously faced up properly, in order to make a perfect joint. The charge was loaded on the spot, and the upper plug had two eyes screwed into it, in order to suspend the cartridge. It had a recess in the centre about an inch deep, into which a piece of inch gas pipe 8 inches long was screwed. The object of the gas pipe was to protect the connection between the electric firing wires and the electric cable. The detonators were put into the case. Three high-tension detonators were used for each shot. The wires protruded through the plug. The connections having been made, the gas pipe was screwed on again, and afterwards filled up with a melted waterproofing mixture, so that there was a perfect joint. The first charge of 27 lb. of roburite was lowered to the bottom of the well and fired by the electric current. He held his hand on the rope. There was a rebound such as Mr. Nursey ex-

plained, and a small earthquake. Upon looking down the well one could see the water spurting up the pipe. In lowering the charge, in order that the cable should not get entangled in the twist of the rope, a man took the cable and rope in his hand, and during the lowering payed both out together hand over hand.

The second shot was fired 50 feet higher up than the first, with 25 lb. of roburite. Both shots went off without the slightest hitch. The week after the work was completed the engineers, Messrs. John Taylor & Sons, wrote stating that since firing the shots the volume of water had been increased to the extent of from 50 to 75 per cent. of the amount previously obtainable. He believed it amounted to something like 50,000 gallons a day. Mr. Nursey stated that he used a Bickford fuse in firing. Mr. Nursey was a great expert on all explosive matters, and therefore it was with deference that he (Mr. Biggwither) gave it as his opinion that if they attempted to torpedo an artesian well in the way that Mr. Nursey attempted the one at Ealing, there would be a great risk when the charge was lighted of its going off at the wrong place. If they used electricity they would have everything under their own control. They only fired the charge at the moment when everything was in order. This was the first experiment of the kind which he had made, and it succeeded perfectly without any hitch, and when the critical moment came he felt thoroughly satisfied with the way in which the whole work had been carried out.

Mr. Walter F. Reid said he had had the pleasure of being associated with Mr. Nursey in some of the operations which had been described. Mr. Nursey's explanations had been so thorough that very little remained for him (Mr. Reid) to say. He had had very large experience of explosives in general, and had carried out a great number of operations. With regard to the bore hole at Ealing, which had just been criticised, he would call attention to the special circumstances of the case. The bore hole was lined for a considerable depth down. They were obliged to avoid injuring the pipes, as damage to them would have been a very serious matter. Consequently the charge was small. He would not advise any one to follow the example of the last speaker in using a cast-iron torpedo for any explosive whatever. Roburite might be a very safe body, but it was unsafe to put any explosive in the neighbourhood of iron, especially when the iron had to be screwed up. It was a very simple thing to make a lead torpedo. The one used at Ealing was very small. It had oval ends, and it was impossible from its construction that it should stick in the pipe of the

bore hole, and of course it was tried beforehand. On the top of the leaden vessel there was a simple brass connection, half of which was soldered on to the lead torpedo before it was charged. Then the explosive was put in, and the other part of the brass connection, which was soldered to a piece of lead pipe long enough to cover the whole fuse, was screwed on. When they got to such depths as 300 or 400 feet of water, the pressure of the water was very likely to get through the very best fuse that could be made; but if the fuse was surrounded by lead, the greater the pressure the tighter the lead would be pressed round the fuse. The acceleration of the burning of the fuse was a subject which gave great trouble to beginners. The acceleration at great depths of water threw out the calculation, unless it had been anticipated and allowed for. This could only be learned by experience, for fuse makers did not refer to it in their catalogues. He had found that the thicker the sides of the fuse the greater the acceleration. He had not ascertained the reason, but the fact ought to be borne in mind.

In the operation at Wapping, it would of course have been possible to put the charge beside the piles and explode it there, but they were precluded from doing that by the proximity of the Thames Tunnel, and it was most important they should not injure that masterpiece of Brunel's. It was very remarkable that when the energy of the explosive and the force required for the work which was to be done were correctly calculated and adapted to one another, there was practically no noise produced. There might be a little vibration, but almost the whole energy was converted into heat. Sometimes, for instance, fragments of iron became nearly red hot when blasted by dynamite or some other high explosive, whereas when the same substance was exploded under conditions in which it was not wholly confined the heat was not so great.

Referring to the demolition of the bridge over the Great Western Railway near Reading, he would observe that the reason the centre arch did not fall at once was that Brunel's brickwork was so good that the two halves of the bridge closed together, as it were, and locked themselves, and the engineers had to have recourse to locomotives. It was quite true that explosives were perfectly under control. He did not regard any explosive as dangerous so long as he had it under his own control. The properties of dynamite were now so well known that those who were familiar with it should not have any accident in its use. There was, however, very great danger attending its use by inexperienced persons. The power of nitro-glycerine was well known, and was much easier to calcu-

late than the power of steam. The total amount of power to be got out of an explosive was, perhaps, a theoretical point, but it was one of very great interest to engineers. Theoretically the most powerful explosive at the present time was liquid hydrogen in combination with liquid oxygen, or the hydrogen might be obtained, perhaps, in a solid form. They could not at present reckon upon any greater force than such a compound would produce. The power of explosives in the future was limited, and he was afraid that they would not in the future get much further than they had already gone.

With regard to the recent fearful disaster at Santander, it might be mentioned that it was a general practice in the shipping trade to ship matches, explosives, petroleum, and things of that nature in the same ship. It could be easily imagined that, when such things were all together in an iron ship, there might be a very great risk of disaster, and it was a great wonder that we did not hear of more ships carrying dynamite disappearing altogether. The folly of some people in dealing with dynamite was perfectly inconceivable. He had taken dynamite out of an oven where a workman had put it to thaw. The favourite practice with miners was to put the cartridges in their pockets, where they might come into contact with matches, or perhaps a pipe. Another favourite practice was to put the cartridges into a heap of stable manure in the mine. Accidents might be caused by this means, owing to the excessive heat generated. When any nitro-glycerine preparation was heated to a high temperature it became extremely sensitive, and the slightest shock would explode it. When using the thawing pans which the explosive companies provided for thawing nitro-glycerine preparations, the miners did not read the instructions, and they sometimes placed the pans on the fire and actually steamed the preparations, using the pans as they would use a glue-pot. One point with regard to some nitro-glycerine explosives was that, after the nitro-glycerine had been absorbed, exudation took place when the explosive came into contact with water, and that was the chief reason why all kieselguhr preparations of dynamite were now being superseded by preparations in which the nitro-glycerine was held in such a manner that the preparation might be kept under water for months without being injured by the exudation of the nitro-glycerine. He held that any explosive containing a hygroscopic material, or one which was acted upon by water, was a thing of the past.

He had carried out many practical operations with explosives. One was the removal of a large mass of iron at the

bottom of a blast furnace. The iron had to be removed without injury to the furnace. The removal was a slow process, but it was carried out by means of nitro-glycerine. A hole was first drilled in the centre of the iron, and dynamite was exploded at the bottom of the hole. In that way a cavity was made at the bottom; and then another small charge was placed and exploded, with water tamping; and that was repeated until radial cracks began to appear. Those again were enlarged, until the whole mass of iron was broken up and removed. It was found very useful to remove the débris with a small magnet. That was much more easy than the usual method. A very interesting operation was carried out at Charlottenburg, near Berlin, not many years ago. A large water-tower, about 98 feet in height and of about the same diameter, had to be removed. It had cost about 300,000*l.* to build, but when it was built they were afraid to put water in it, lest the great weight should prove too much for the structure. The tower was surrounded by houses, and there arose the question how it should be got down without injury to the houses. The removal was effected by dynamite; small charges of from 1½ to 2 lb. were detonated underneath the columns, and the work fell in sections. Finally, simultaneous charges were exploded under twenty columns, and the whole structure fell down. About 393,000 tons of material were removed in that way, the quantity of dynamite used being about 440 lb. One of the largest operations of modern times was the removal of the Iron Gates of the Danube. In that case the contractor used powerful machinery to crush the rock, and then the fragments were removed by means of dredgers. The rock was extremely hard, and it was found more economical to remove it in that way than to use dynamite. That was extremely interesting to engineers, because it was a return to mechanical power in place of explosives. He did not think that explosives were used to the extent to which they should be in removing impediments under water, especially iron. There were many cases in which blasting could be used at a small cost and with a small quantity of explosives. The removal of the piers, as described by Mr. Nursey, was an instance of that. A 2-oz. cartridge of dynamite would cut through any submerged chains which they might come across. A line of railway might be cut through in about three minutes if the explosives were ready. In carrying out work under water, success depended entirely upon the means used for securing the joints. Difficulties were met with in the use of electricity. Of course there had to be a thoroughly non-conducting surface all round the whole of the wires, and then the machine had to be brought to the spot; whereas, if a fuse was used, all that was

wanted was a box of matches. In making the joints for subaqueous explosions, it was necessary to have something better than the usual tallow joint. Tallow would keep out water if there was no pressure; but the best thing was to place a piece of india-rubber tubing at every joint.

Mr. H. A. Krohn said Mr. Nursey's paper dealt almost entirely with operations in which the author had taken a personal part. To him (Mr. Krohn) that fact constituted the chief interest of the paper. Perhaps the most important lesson which one could get from Mr. Nursey's description of his operations was the immense importance, in all blasting operations of any magnitude, of having really skilled and scientific superintendents. It was very often the case that the work was put into the hands of persons who were perfectly competent in ordinary mining operations, but really did not know the a, b, c of the business when they came to deal with a large blast. In such cases there was usually a failure of some kind, and it might be that lives and time and money were lost. From that point of view it was a fortunate thing that the anarchists were not distinguished for very perfect education in the use of explosives. It might not be known to the meeting that the English Home Office authorities would not license rackarock, which was one of the explosives used in the Hell Gate blast. It was a composition made by saturating chlorate of potash in dead oil or nitro-benzole. The saturation was effected on the spot where the blasting took place. That was a very convenient thing for countries in which such dangerous operations were permitted.

With regard to the Santander disaster, which Mr. Nursey had so graphically described, it might be interesting if he (Mr. Krohn) recalled a somewhat similar explosion in San Francisco about the year 1886, which, happily, was not attended by such terrible results. A sailing vessel named the *Parallel*, which was laden with a similar cargo to that of the ship at Santander, was lying off San Francisco. She carried bar iron, coal, matches, petroleum, and 42 tons of American dynamite. The vessel ran on the rocks and was battered by the surf, so that the salt water penetrated to the hold and caused the nitro-glycerine to exude. The shock of the grounding of the vessel upon the rocks exploded the nitro-glycerine. The dynamite which exploded at Santander was, he thought, of the kind generally used in mining in the north of Spain. That was not No. 1 dynamite, which contained 75 per cent. of glycerine, but a much lower quality, containing from 25 to 30 per cent. The dynamite at San Francisco was a high grade American dynamite, and the result was extraordinary. A very fine hotel

about a hundred feet above the shore was totally wrecked, and so were many houses in the vicinity. Enormous fragments of rock were hurled some half a mile inland. Windows seven or eight miles distant were broken; and it was said that the sound of the explosion was heard about a hundred miles off. The people in the neighbourhood were warned in time to get out of the way, and no lives were lost, but four or five unfortunate coast-guardsmen were injured. That was probably the most important explosion of dynamite on board ship, in respect of quantity.

He agreed with the author as to the wickedness of repeating the fallacy with regard to the safety of dynamite when exposed to the action of fire. In a book on blasting which professed to be a manual of the subject, the statement was repeated only last year. It was said that dynamite might be held in the hand and burnt without risk. As to thawing accidents, they, of course, would continue as long as nitro-glycerine preparations were used in the winter. The most precise regulations might be drawn up, and the utmost efforts might be made to cause miners to use safe vessels for thawing dynamite or gelatine, but miners would not heed the regulations or use the proper vessels. As Mr. Reed had stated, one of the favourite methods among the miners was to put the cartridge into their pockets. It was related a year or two ago, that a miner came home wet and hung his trousers over the stove, and then a youth, who lodged with the miner, came in and leaned over the stove. In the pocket of the miner's trousers there was a gelignite cartridge, which exploded in due course, and the lodger was blown to pieces. The same carelessness and recklessness occurred in the use of gunpowder. The miners made cartridges in their dwelling houses, and smoked their pipes while so doing, and thus caused explosions. Nothing would induce men of that class to take proper precautions.

With regard to cargoes of ships, some persons supposed that cargoes of explosives were carried on passenger ships. That might be the case with foreign vessels, but it was not so under the British flag. He might also point out that such accidents as that which recently occurred at Santander would be impossible in this country, where vessels carrying explosives had to discharge their cargoes at a buoy outside the docks.

Mr. Nursey, in replying to the discussion, first referred to the circumstance that Admiral Colomb had expressed surprise that he (Mr. Nursey) preferred nitro-glycerine compounds to explosives of the Sprengel class. He preferred lithofracteur years ago, because at that time the Sprengel compounds were not in use and were hardly known. The reason why he had

not referred to the other kinds of explosives more specifically was that he had described them in previous papers which he had read before the Society. He had used roburite under certain conditions, and he had given it a very good character, and he was prepared still to give it a good character; but under certain circumstances he preferred not to use it, for the very reasons which Admiral Colomb had given, which were that it was hard, and that it was hygroscopic and had to be put in a tin for protection when it was to be used under water. He liked an explosive which was powerful, which was plastic, and could be pressed into cracks and crannies, and which would stand the accidental chance of being immersed in water for a long time. Though roburite was an excellent explosive, he had not yet met with a case in which he would use it in preference to dynamite. With regard to the remark of Admiral Colomb that roburite was three or four times as strong as gunpowder, he (Mr. Nursey) was quite prepared to endorse that statement. He (the speaker) observed that surprise had been expressed that he did not use electricity for firing his charges. He had used electricity where he had had to fire a number of shots simultaneously, and there were conditions in which he should certainly prefer electricity. But he placed great reliance upon those explosives and those methods of firing which he had found satisfactory in practice, and which had never failed him. He had always found the ordinary cap and fuse answered very well. Mr. Biggwither had remarked upon the charges in the well being very small. Mr. Reid had ably answered that point by showing that they had to avoid doing damage to the metal lining of the bore hole. He was not at all sure that a larger charge would have brought more water out of the chalk in that instance, as it was not, geologically, a strictly water-bearing chalk. To prevent the possibility of the charge jamming, he lowered a dummy torpedo several times and drew it up again, and made sure beforehand that the way was perfectly clear, as he had stated in the paper. He went through the same process again immediately before lowering the torpedo by lowering a weighted tube to the proper depth, and bringing it up again carefully. No hitch whatever occurred when the charge itself was lowered. It was impossible to say that a hitch might not occur on some future occasion, but he should not anticipate such a thing if he followed the lines upon which he had previously worked. He did not agree with Mr. Reid that it was dangerous to thaw dynamite in stable manure. He had often done so himself, and as there was only a gentle warmth, the thawing was very effectually and safely carried out.

Mr. Nursey concluded by producing a piece of gun-cotton which had been in his possession since the year 1855. He then burned a small piece in the presence of the meeting, and showed that the gun-cotton had retained its active properties after the lapse of nearly forty years. The sample of gun-cotton was perfectly preserved, and was a remarkable example of the stability of that explosive compound when properly made.

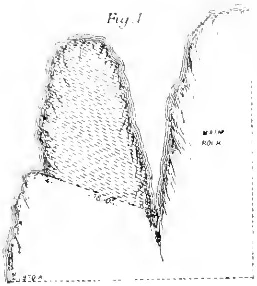


Fig. 1

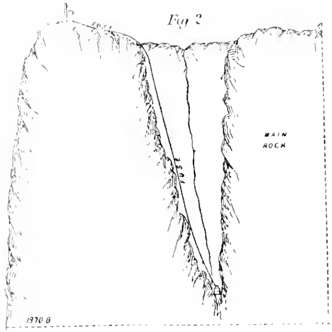


Fig. 2

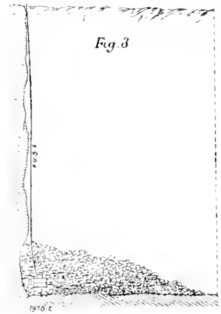


Fig. 3

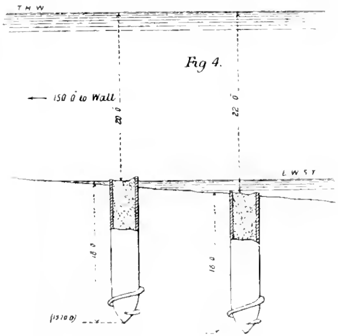


Fig. 4.

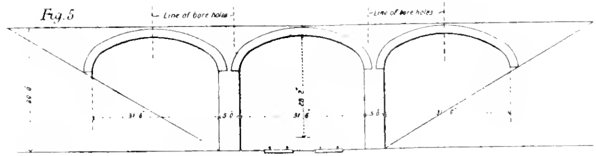


Fig. 5

Fig. 6.

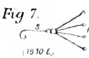


Fig 7.

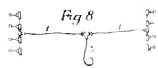


Fig 8


Fig 9

Obituary.

Alfred Wilkinson Jones was elected a Member of the Society in 1878, and was a foreign member at the time of his death, which occurred on January 12, 1893. Mr. Jones was the third son of the late Mr. Thomas Jones, formerly agent at Newport to the Ebbw Vale Iron and Steel Company, and was born on Oct. 24, 1850. After completing his education at Neuwied-on-Rhine, he became a pupil of Mr. J. J. Bodmer, inspecting engineer, and subsequently was a partner. Upon the retirement of Mr. Bodmer, about three years since, Mr. Jones took over the business, which he carried on in London and in Duisburg-on-Rhine, residing at the latter place, where he died. Mr. Jones contributed a paper to the Society in 1879, on modern tramway construction. The deceased gentleman was an accomplished musician, and passed with high honours the examination in connection with the College of Organists.

Edmund Cooper, who was elected a Member in 1862, was son of the late Mr. Robert Cooper, of Scarning, Norfolk, where he was born on May 1, 1818. He died on June 22, 1893, at Wallington, in Surrey. He was a pupil of the late Mr. I'Anson, and afterwards, in 1841, was Assistant Surveyor to the Surrey and Kent Commissioners of Sewers. Upon the consolidation of that body with those of other districts as the Metropolitan Commission of Sewers, Mr. Cooper was retained as a District Clerk of Works, and was subsequently appointed engineer to one of the districts. In 1856 he was appointed an Assistant Engineer to the Metropolitan Board of Works, and took charge of the eastern portion of the district in charge of the Board, and extensive works connected with the Metropolitan Main Drainage and the Thames Embankment were carried out under his supervision. Owing to ill health Mr. Cooper retired from the service of the Board of Works in 1870, and took no further active part in the profession.

Samuel Thomas Price was elected a Member in 1883, at which time he was manager of the Market Harborough Gas Works. He had previously held similar appointments at the Worcester Gas Works and at the Corporation Gas Works, Droitwich. He was born in 1847, and died on July 6, 1893.

Frantz Grashof was elected an Honorary Member in 1867. He was born on July 11, 1826, at Düsseldorf, where his father was one of the professors at the Gymnasium. Having passed through all the classes, the son left the Gymnasium in 1843, and commenced his professional career in the Royal Iron Foundry, Berlin. He then conceived the idea of entering the German Navy, and as a preliminary step he joined a Hamburg merchantman for three years. In 1852, however, he resumed his scientific studies, passing successfully in 1854 the State examinations for mathematics and mechanics. He was then appointed to teach those subjects in the Berlin Technical Institute, and in 1855 he was also appointed Director of the Department of Weights and Measures. In 1860 the University of Rostock conferred upon him the honorary degree of Doctor of Philosophy. Three years later he was appointed Professor of Applied Mechanics at the Polytechnic College at Carlsruhe, which position he continued to occupy to the time of his death. Dr. Grashof was created a Councillor of State in 1866, a Privy Councillor in 1874, and was elected a member of the First Chamber of Legislature in 1877. He was the founder, and for thirty years a director of the German Association of Engineers, which now numbers nearly 9000 members, who are distributed all over the world.

William Jordan was elected a Foreign Member in 1891. He was born in 1850, and died on November 19, 1893. He served for a period of seven years with Messrs. Bryan, Donkin and Co., Engineers, London, and left England in 1876 to take up the appointment of manager at Messrs. Ahmuty and Co.'s Howrah Foundry, Bengal.

SOCIETY OF ENGINEERS.

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